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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE

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PROPERTIES OF SOME EXPANDED PLASTICS

AND OTHER LOW-DENSITY MATERIALS

By Benjamin M. Axilrod and Evelyn Koenig
National Bureau of Standards



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SUMMARY

Various mechanical and physical properties of several expanded plastics and other low-density materials of interest for aircraft applications, such as heat insulation of the core of a sandwich material, were investigated. The materials included in the program were cellulose acetate plastic, polystyrene, a urea-formaldehyde resin, a zein product, hard rubber, balsa wood, and cellular glass. The properties studied included density, thermal conductivity, dimensional stability on exposure to extremes of temperature and relative humidity, resistance of the materials to chemicals, and flexural and compressive strengths and moduli of elasticity.

The density of the polystyrene expanded material was a fourth, urea-formaldehyde one-half, and hard rubber and cellulose acetate about the same as that of the low-density balsa, 0.08 gram per cubic centimeter. The other materials had greater densities than balsa.

The hard rubber had the lowest thermal conductivity of the materials tested and compared favorably with commercial insulating materials.

The glass and polystyrene expanded materials exhibited the smallest changes in weight and in dimensions on exposure to extremes of temperature and relative humidity. Only the glass material remained unaffected after 7 months' outdoor exposure. The least dimensional and percentage weight changes on immersion in various chemicals and after drying were exhibited by the glass product and hard rubber in that order.

Balsa was greatly superior to the other materials in modulus of rupture in bending and in flexural modulus of

of elasticity. The hard rubber had the highest modulus of rupture and flexural modulus of elasticity of the expanded organic materials. On a stiffness-weight basis, the flexural properties of the polystyrene approached those for the balsa. Balsa was much superior to the other materials in compressive properties.

INTRODUCTION

Recently, various expanded plastics of low-density and porous structure have been developed. Some information on the mechanical properties of four such materials, cellular cellulose acetate, calcium alginate, and two other materials believed to be natural or synthetic sponge hard rubber, has been reported. (See reference 1.) As the density and cell structure can be varied in these expanded materials, they seem promising for several applications in the field of aircraft construction. They may have low enough thermal conductivities to make them useful for heat insulation. If their strength-density properties are reasonably good, the expanded products may find application in the core of a sandwich material having high-strength, high-density faces. In this connection it is worth noting that balsa wood is being used successfully as a core material in the structure of the Mosquito bomber. (See reference 2.)

The purpose of this investigation was to obtain information regarding the properties of several types of expanded materials which are available from commercial sources. With this information it should be possible to select materials for specific applications. The properties investigated were density, thermal conductivity, dimensional stability on exposure to extremes of temperature and relative humidity, resistance of the materials to water, lubricating oil, gasoline and other chemicals, and flexural and compressive strengths and moduli of elasticity.

The expanded plastics included in this investigation were cellulose acetate, polystyrene, a urea-formaldehyde resin, and a zein (protein) base product. Other materials studied were a cellular hard rubber, balsa wood, and a cellular glass.

This investigation, conducted at the National Bureau of Standards, was sponsored by and conducted with the financial assistance of the National Advisory Committee for Aeronautics.

Acknowledgment is due to Mr. L. K. Hyde and O. S. Peters Company, Washington, D. C., for suggesting a method for using a Southwark-Peters plastic extensometer to give load-deformation records in compression testing.

MATERIALS

The materials tested and their description, including some data from the manufacturer, were as follows:

(a) The cellulose acetate expanded plastic was furnished in sheets 0.5 inch thick with cylindrical cells oriented perpendicularly to the plane of the sheet. This material, supplied by E. I. du Pont de Nemours and Company, was "formed by first mixing cellulose acetate with solvent, treating it under variable temperature and pressure conditions, and expanding it by suddenly releasing the pressure."

(b) The polystyrene expanded plastic was supplied by the Dow Chemical Company under the designation "Q-103 Styrofoam," in sheets 1 inch thick with closed, approximately spherical cells about 1/16 inch in diameter.

(c) The protein-base sponge was made from zein with 40 percent plasticizer and was supplied in sheets about 1.4 inches thick. This material, manufactured by the B. F. Goodrich Company under the designation "hard Anak sponge" has a closed, spherical cell structure with cells of approximately 1/32-inch diameter. The faces have a thin skin of the same composition as the core.

(d) The urea-formaldehyde resin expanded plastic, "Resin Foam," was made by the Goodyear Tire and Rubber Company in the form of slabs about 2 inches thick with approximately spherical interconnecting cells. The manufacturer states that the material "is made from urea-formaldehyde resin frothed with the aid of a frothing material and set by the addition of a setting material after it is poured in the desired shape."

(e) The hard rubber expanded material was made in slabs 1 inch thick by the United States Rubber Company and designated "#2266 hard cellular board." This product contains 35 percent filler and 10 percent softener and has a skin of the same composition as the core. The material has closed, approximately spherical cells about 1/50 inch in diameter with a few larger cells, about 1/16 to 1/8 inch in diameter.

(f) Balsa wood, in two densities, was supplied in the form of boards 2 to 4 inches thick by the Naval Air Experimental Station, Navy Yard, Philadelphia, Pa.

(g) Glass, in the form of a closed, spherical cell product, called "Foamglass," was furnished in 2-inch-thick slabs by the Pittsburgh Corning Corporation. The Foamglass was "cellulated by the evolution of internal gas at high temperatures."

TEST PROCEDURES AND EQUIPMENT

The procedures employed were similar, in general, to those described in Federal Specification L-P-406a. (See reference 3.) The specimens for the various tests were conditioned at 77° F and 50 percent relative humidity for at least 2 days prior to test and tested under these conditions unless otherwise specified.

Weight and Dimensional Measurements

The specimens were weighed on an analytical balance of the magnetically damped type which permits rapid weighing. In measuring the dimensions of the specimens it was found that some of the materials were soft enough that the foot of an ordinary dial thickness gage would sink in a considerable amount. A Schiefer compressometer (fig. 1) was used for dimensional measurements since with this instrument a light controllable load can be applied to the dial foot. (See reference 4.) For most measurements the force on the 1-inch-diameter foot was adjusted to 0.1 pound. In this instrument, the lower dial graduated in 0.001-inch units indicates the thickness of the specimen and the upper dial, the pressure applied. For some tests the changes in softness of the materials were estimated with the compressometer by measuring the dimensions for two different pressures.

The density of the test specimens was calculated from weight and dimensional measurements.

The thickness of the test specimens was the same as that of the sheets supplied, except for the balsa, in which case the specimens were taken from 1-inch-thick planed boards. The lengthwise direction was taken along the length of the sheet; if the sheet was square, the lengthwise direction was

arbitrarily chosen. For the balsa the lengthwise direction was with the grain.

Thermal Conductivity

The materials were tested in an 8-inch guarded hot plate apparatus in a manner similar to that described in Federal Specification LLL-F-321b. (See reference 5.) The specimens, 8 by 8 inches square, were dried in an oven at 140° to 150° F for about 16 hours prior to test.

Resistance to Extremes of Temperature and Humidity

The materials were subjected to the accelerated service tests described in Method 6011, Federal Specification LP-406a. (See reference 3.) The conditions in these tests are as follows:

Test I: 24 hours at 140° F, 88 percent relative humidity
24 hours at 140° F, in circulating-air oven

Test II: 72 hours at 140° F, in circulating-air oven

Test III: 24 hours at 160° F, 70 to 75 percent relative humidity
24 hours at 160° F, in circulating-air oven

Test IV: 24 hours at 175° F, about 100 percent relative humidity
24 hours at 175° F, in circulating-air oven

Test V: 24 hours at 175° F, 70 to 75 percent relative humidity
24 hours at -40° F, dry-ice refrigerated box
24 hours at 175° F, in circulating-air oven
24 hours at -40° F, dry-ice refrigerated box

Duplicate specimens of each material, 3 by 3 inches by the thickness, were subjected to the five tests in the order listed, and were weighed and measured initially and after each exposure period.

Accelerated Weathering

The materials were subjected to alternate exposure to a temperature of 150° F in a circulating-air oven and to moisture in a fog chamber at a temperature of 77° F. The daily

schedule included 2 hours in the fog chamber, 2 hours in the oven, 2 hours in the fog chamber, and 18 hours in the oven. The duration of the test was 240 hours. Two specimens of each material, 2 by 2 inches by the thickness, were weighed and measured initially and at the end of the test.

Natural Weathering

Samples of the materials were placed outdoors on March 15, 1944, in Washington, D. C., on exposure racks that faced south and were inclined at 45° to the horizontal. Two flexure test specimens were cut from each sample prior to the outdoor exposure. It is planned to make flexure tests on specimens taken from the samples after a year's exposure. The samples were examined May 15 after 2 months' exposure, and on October 17 after 7 months' exposure.

Resistance to Chemicals

The materials were tested for their resistance to the following chemicals: water, 95 percent ethyl alcohol, ethylene glycol, glycerol, diacetone alcohol, SAE 10 motor oil, heptane, and an aromatic gasoline blend consisting of 60 percent 100-octane gasoline, 20 percent toluene, 15 percent xylene, and 5 percent benzene. One specimen of each material, 2 by 2 inches by the thickness, was weighed and measured before and immediately after immersion for 7 days. The measurements were repeated after 7 days of air drying. Each specimen was placed in a separate container. A duplicate set of specimens was subjected to the 24-hour water absorption test described in Method 7031, Federal Specification L-P-406a. (See reference 3.)

The softening of the specimens immersed in chemicals was measured with the compressometer in the following way. The length, width, and thickness measurements before and after immersion and on drying the specimen were made with both a 0.1- and a 1-pound force on the dial foot. The difference in hundredths of an inch between the measurements with the two loads on the dial foot is defined as the softness index.

Flexure Tests

Flexure tests were made with a self-aligning, adjustable-span flexure jig (fig. 2) mounted in a universal hydraulic

testing machine. After the flexure jig had been centered and aligned relative to the pressure piece A, it was kept in place with a magnetic chuck B. The span could be subsequently adjusted to any value from 1.6 to 9 inches by means of the calibrated screw C without recentering or realining. The support pieces D each had a radius of 0.125 inch and the pressure piece a radius of 0.50 inch. The deflection of the specimen at the center of the span was indicated by a Southwark-Peters plastics extensometer E attached to an equal-arm lever F in contact at one end with the lower face of the test specimen. A flat piece of plastic was placed between the specimen and the end of the lever to keep the edge of the lever from pushing into the test specimen. With this apparatus and the associated recorder, load-deflection graphs were obtained during the testing. A specimen in place ready for testing is shown in figure 3.

The testing machine had a capacity of 2400 pounds and a low range of 240 pounds which was used for most of the tests. The estimated error of the load indicator when the load-deflection graphs were made was less than 0.5 pound for the 240-pound range. The deflection indicator was accurate to within 5 percent in the range of 0.01 to 0.1 inch and 2 percent in the range 0.1 to 0.4 inch.

The specimens were 2 inches wide and had a depth equal to the thickness of the material; the span-depth ratio was maintained at 7 to 1. Tests were made for the two grades of balsa with a flexure jig of larger span to obtain modulus of rupture values for a span-depth ratio of 16 to 1.

The modulus of rupture s_r was calculated from the usual formula:

$$s_r = \frac{3Pl}{2bh^2}$$

where

P maximum load

l span

b width

h depth of the specimen

The slope of the straight portion of the load-deflection graph was determined, and from this the "effective flexural

modulus of elasticity," E_f , neglecting the deflections due to shear and to concentrated loads at the supports, was calculated as follows:

$$E_f = \frac{P}{X} \frac{l^3}{4bh^3}$$

where P/X is the slope of the load-deflection graph. The other quantities were defined for the preceding equation.

Tests were made both with and without plywood or acrylate resin pads at the support pieces to determine the effect of the local deformation on the flexural modulus of elasticity.

Compression Tests

The materials were subjected to flatwise and edgewise compression tests. Two universal hydraulic testing machines were used to accommodate the wide range of maximum loads required for the various materials. One had ranges of 240, 1200, and 2400 pounds and the other had ranges of 2400, 12,000, and 60,000 pounds. Special bearing blocks were constructed with brackets (fig. 4) to permit using the Southwark-Peters plastics extensometer for deformation measurements. With this equipment and the associated recorder, load-deformation graphs were obtained during the test.

The flatwise compression test specimens were 3 inches square with the height equal to the thickness of the sheet except for the balsa. The latter specimens were cut from 1-inch-thick planed boards. Tests were made both with and without an aluminum alloy spherical seat. Figure 5 shows a polystyrene specimen ready for test with the spherical seat in place and the extensometer attached to the brackets. When the spherical seat was used, it was adjusted so that the plane surface of the top part was parallel to the surface of the upper fixed bearing block.

The edgewise compression tests were made on lengthwise and crosswise specimens the heights and widths of which were twice the thickness. The balsa specimens were taken from 1-inch-thick planed boards. The ends of the specimens were made flat and square on a sanding disk. Most of the materials were tested without the spherical seat. A balsa specimen in place for edgewise compression testing is shown in figure 6.

RESULTS AND DISCUSSION

Density

The densities of the specimens were determined in many of the tests, and the values are shown in the tables. The approximate average densities of the expanded materials in grams per cubic centimeter are as follows: cellulose acetate 0.08 to 0.09; polystyrene 0.02; zein 0.16 to 0.18; urea-formaldehyde 0.04; hard rubber 0.07 to 0.08; low-density balsa 0.07 to 0.09; high-density balsa 0.16 to 0.32; glass 0.16 to 0.17.

Thermal Conductivity

The results of the thermal-transmission measurements are given in table I. The hard rubber had the lowest conductivity, the value for K being 0.25 Btu per hour per square foot per degree Fahrenheit per inch at 95° F. This compares favorably with many of the rigid and most of the fibrous commercial insulating materials. (See references 6 and 7.)

Resistance to Extremes of Temperature and Humidity

The results of these tests are given in table II. The least weight changes, less than $1\frac{1}{2}$ percent, were shown by polystyrene.¹ The glass also exhibited very slight changes in weight. The hard rubber, zein, and low-density balsa exhibited weight changes of 5 to 20 percent when subjected alternately to high and low relative humidities.

The least dimensional changes were exhibited by the inorganic product glass, and the polystyrene; the changes for these materials were generally less than 0.5 percent. The glass material crumbles at the surface of contact on handling, which explains the negative trend of the changes. The other materials exhibited changes of about 1 to 5 percent when exposed alternately to high and low relative humidity.

¹In contrast to the other organic materials, the polystyrene regularly lost weight during a high-humidity period and gained weight during the following low-humidity condition. The reason for this is not known, but since the changes were small this behavior may not be significant.

Accelerated Weathering

The changes in weight and dimensions after the 240-hour oven-fog test are given in table III. The resultant changes in weight were less than 1 percent for cellulose acetate, low-density balsa, and glass, and between 1 and 2 percent for the other materials. The resultant changes in the dimensions were between 1/2 and 3 percent for all materials and nearly all of the changes were negative.

Natural Weathering

The condition of the samples exposed out doors is shown in figures 7 and 8. The results of warp and shrinkage measurements are given in table IV for the 7-months' exposure period. The inorganic glass product exhibited the least shrinkage and warp and appeared unaffected by the exposure.

The polystyrene exhibited very little warp or shrinkage, but the face exposed to the light had become embrittled with the result that erosion by the wind reduced the sample to half its original thickness. The specimens of polystyrene which had been subjected to the heat-fog accelerated weathering test did not show this surface embrittlement. Specimens of polystyrene were subjected to the ultraviolet light-fog accelerated weathering test described in Method 6021 of Federal Specification L-P-406a (reference 3); the material turned yellow and the surface became sufficiently brittle so that it could be eroded by blowing a stream of air over the surface. This behavior was similar to that observed on the specimen exposed outdoors for 7 months.

The greatest dimensional change of the hard rubber in either direction was less than that of the balsa in the cross-grain direction in which the greatest change occurred for this wood. However, the hard rubber developed a greater warp than the balsa. The changes in the dimensions of the cellulose acetate and zein were 10 percent or more, and these materials warped badly.

Resistance to Chemicals

The data for weight and dimensional changes for the materials subjected to immersion in chemicals and to air-drying are given in tables V, VI, and VII. The data on softness indices for the materials before and after testing are given in table VIII.

The lowest percentage weight changes on immersion were shown by the glass. In making a comparison of percentage change in weight, however, the densities also need to be considered. For example, glass, hard rubber, and polystyrene, on absorbing equal weights of the same chemical would have percentage increases in weight of 1:2:8 as the densities are in the ratio 8:2:1. Hard rubber and the low-density balsa are of about the same density and are readily compared. The hard rubber absorbed much less chemical in all instances than the balsa.

The hard rubber exhibited dimensional changes of less than 1 percent in all chemicals except the gasoline blend for which changes of 1 to 2 percent were noted. This expanded product compared favorably with glass in this respect. The low-density balsa in the direction of the grain exhibited dimensional changes of less than 1 percent for all chemicals but perpendicular to the grain changes of 2 to 3 percent were obtained for several of the chemicals including the alcohols. The cellulose acetate dissolved in acetone and diacetone alcohol and showed changes of about 5 percent in the length and width for immersion in ethyl alcohol and ethylene glycol. The polystyrene was dissolved by acetone and the gasoline blend, shrank about 45 percent on immersion in heptane, and swelled about 22 percent in diacetone alcohol. The remaining five chemicals caused dimensional changes up to 1.5 percent. The dimensions of the zein were principally affected by the alcohols and acetone, and the changes in dimensions for the other chemicals were a few percent. The urea-formaldehyde material exhibited dimensional changes of less than 1 percent for motor oil, heptane, and glycerol and less than 5 percent for the other chemicals employed.

The 24-hour water absorption test (table VII) gave results comparable to those obtained in the 7-day immersion in water tests.

From the data in table VIII it is concluded that zein is softened by water, ethyl alcohol, ethylene glycol, and diacetone alcohol; and that hard rubber is softened by the gasoline blend. The slight changes in softness index obtained in other instances are not considered significant.

Flexure Tests

The results of the flexure tests are given in table IX. Sample load-deflection graphs are shown in figure 9.

None of the materials tested had flexural modulus of elasticity values comparable to the balsa. The highest value obtained for a synthetic material was about 5000 psi for hard rubber compared to a value of 195,000 psi for balsa of slightly higher density. Unsatisfactory load-deflection graphs were obtained with the glass so that its flexural modulus of elasticity was not obtained. The glass underwent intermittent crumbling at the pressure and support pieces and, since the deflection was measured relative to the supports, the resulting load-deflection graphs were very irregular.

The strength of the balsa was much greater than that of the other products. The modulus-of-rupture values for the strongest materials were as follows: high- and low-density balsa, 5000 and 800 psi, respectively; glass, 100 psi; and hard rubber, 90 psi.

When the materials are compared on the basis of specific strength values, the polystyrene is comparable to the balsa in stiffness and in specific modulus of rupture. The hard rubber is the second best synthetic material with a tenth of the stiffness and a tenth of the specific modulus of rupture of balsa of the same density.

The flexure test data for balsa compare reasonably well with values reported by the Forest Products Laboratory. (See reference 8.)

From the tests with and without the pads at the support pieces, it is concluded that the local deformation due to concentrated loads did not affect the flexural modulus of elasticity data appreciably for the polystyrene and hard rubber. In the case of the low-density balsa, however, tests without plastic pads resulted in flexural modulus of elasticity values less than half of the corresponding values obtained with plastic pads.

Compression Tests

The data for the flatwise and edgewise compression tests are given in tables X and XI, respectively. Average stress-strain curves for the various materials are shown in figures 10 and 11. Typical load-deformation graphs as obtained on the recorder are illustrated in figures 12 and 13.

The cellulose acetate with the fibers or cells oriented in the flatwise direction exhibited the highest flatwise

compressive modulus of elasticity of the synthetic organic materials, 3400 psi. The average value obtained for balsa of slightly lower density was about 1500 psi.

The flatwise compressibility of the balsa is apparently very sensitive to the density; when the density was increased two to three times, the effective modulus of elasticity values were multiplied tenfold or more. The polystyrene, zein, and hard rubber were about equal in flatwise moduli of elasticity, exhibiting values of 300 to 600 psi. The tendency of the glass to crumble at the bearing surfaces makes the modulus of elasticity data for this material uncertain.

In the edgewise compression tests the method of measuring the motion of the heads (fig. 6), a non-averaging method, was checked with a pair of dial gages placed symmetrically relative to the axis of the testing machine heads. Good agreement was obtained by the two methods for edgewise tests of low-density balsa, both lengthwise and crosswise. Considerable error, however, was obtained for the high-density balsa the modulus of elasticity of which was five to seven times that of the low-density balsa. As all the synthetic products exhibited moduli of elasticity much less than the low-density balsa, the non-averaging arrangement shown in figure 6 was considered satisfactory for these materials.

The hard rubber had the highest effective modulus of elasticity of the expanded organic materials in the edgewise tests. The value for the rubber product was about 4000 psi compared to 100,000 psi lengthwise and 3500 psi crosswise for balsa of the same density. The compressive moduli of elasticity obtained for the hard rubber in the edgewise tests were much higher than those obtained in the flatwise tests. The skin on this material probably caused most of the increase. The polystyrene and zein exhibited compressive moduli of about 800 psi in the edgewise tests. The modulus of elasticity/density ratio for polystyrene is about a fortieth of the corresponding ratio for the low-density balsa in the lengthwise direction and about equal to the corresponding ratio in the crosswise direction.

The compressive yield stress of the low-density balsa for the lengthwise direction was 700 psi compared to 50 psi for hard rubber and 16 psi for polystyrene.

The compression test data for balsa compare reasonably well with the values given in reference 8.

CONCLUSIONS

1. The density of the polystyrene expanded material was a fourth, urea-formaldehyde a half, and hard rubber and cellulose acetate about the same as that of the low-density balsa, 0.08 gram per cubic centimeter. The densities of the zein and glass expanded materials were greater than that of the low-density balsa.
2. The hard rubber had the lowest thermal conductivity of the materials tested and compares favorably with many of the rigid and most of the fibrous commercial insulating materials.
3. The least weight and dimensional changes in the tests involving extremes of temperature and humidity were exhibited by the glass and polystyrene expanded materials.
4. The organic products were all affected to some extent by 7 months' outdoor exposure; the glass product was unaffected.
5. The least dimensional changes and lowest percentage weight changes on immersion in various chemicals were exhibited by glass and hard rubber in that order. For these materials the dimensional changes were less than 1 percent except in the case of hard rubber in an aromatic gasoline blend.
6. Balsa was much superior to the other materials in flexural properties. In flexure, its modulus of elasticity was forty times and its modulus of rupture was nine times the values for hard rubber of the same density, the strongest organic synthetic material. When the density is taken into account, polystyrene approached the balsa in specific flexural modulus of elasticity and specific modulus of rupture.
7. Balsa was much superior to the other materials in compressive properties. The cellulose acetate with cylindrical cells oriented perpendicularly to the plane of the sheet had a flatwise compressive modulus of elasticity that compared favorably with the corresponding value for balsa of the same density. The edgewise compressive modulus of elasticity for hard rubber, the most rigid of the synthetic organic products, was 4 percent of the edgewise value for the low-density balsa in the lengthwise direction. The compressive yield stress for the low-density balsa in the lengthwise

direction was more than ten times the value for the hard rubber product.

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TABLE I.- THERMAL CONDUCTIVITY OF LOW-DENSITY MATERIALS

Material	Thickness (in.)	Density, oven-dried		Thermal conductivity ¹ , K (Btu/hr/ft ² /°F/in.)
		(lb/ft ³)	(g/cm ³)	
Cellulose acetate ²	0.56	5.3	0.085	0.40
Polystyrene	1.11	1.0	.016	.35
Hard rubber	.98	4.3	.069	.25
Balsa, low-density ³	1.00	5.8	.093	.32
Balsa, high-density ³	.74	10.0	.16	.41
Glass ⁴	1.0	10.3	.165	.53

¹The mean temperature for these tests was in the range 92° to 100° F.

²The test specimen consisted of two thicknesses of this material, giving a total thickness of 1.12 in.

³The test specimen consisted of pieces 4 by 8 in. butted together at the edges to form 8-in. squares; all pieces were cut from the same board.

⁴The material used in this test was from a different shipment than that used for the other tests on expanded glass. The specimen was oven-dried at 250° F prior to test.

TABLE II.- CHANGES IN WEIGHT AND DIMENSIONS OF LOW-DENSITY MATERIALS IN ACCELERATED SERVICE TESTS INVOLVING EXTREMES OF TEMPERATURE AND HUMIDITY¹

Material	Test I		Test II		Test III		Test IV		Test V			
	Change after 24 hours at 140°F, 88% R.H. (%)	Change after 24 hours at 140°F in oven (%)	Change after 72 hours at 140°F in oven (%)	Change after 24 hours at 160°F, 70-75% R.H. (%)	Change after 24 hours at 160°F in oven (%)	Change after 24 hours at 175°F 100% R.H. (%)	Change after 24 hours at 175°F in oven (%)	Change after 24 hours at 175°F 70-75% R.H. (%)	Change after 24 hours at -40°F (%)	Change after 24 hours at 175°F in oven (%)	Change after 24 hours at -40°F (%)	
W E I G H T												
Cellulose acetate	+ 2.7	- 6.0	- 0.2	+ 3.4	- 3.6	+ 6.9	- 6.8	+ 1.6	+ 0.3	- 4.6	+ 2.5	
Polystyrene	- 1.4	+ 0.3	0.0	- 1.0	+ 0.3	- 0.5	+ 0.2	- 1.2	+ 0.3	0.0	+ 0.7	
Zein	+ 5.2	- 8.6	- 0.4	+ 4.8	- 5.3	+ 11.4	- 11.2	+ 5.0	- 0.2	- 7.2	+ 0.5	
Urea-formaldehyde	+ 0.4	- 3.4	- 0.2	+ 1.6	- 2.3	+ 6.8	- 7.4	+ 0.2	+ 0.4	- 3.4	+ 1.7	
Hard rubber	+ 11.6	- 11.5	- 2.7	+ 5.2	- 5.2	+ 19.8	- 19.8	+ 10.4	+ 0.2	- 11.0	+ 0.2	
Low-density balsa	+ 4.3	- 10.5	- 0.2	+ 6.2	- 6.7	+ 14.6	+ 15.0	+ 3.9	+ 0.2	- 8.6	+ 1.2	
Glass	- 0.6	- 0.4	- 2.0	- 0.4	- 0.8	+ 2.6	- 4.4	- 0.2	+ 0.4	- 1.0	- 1.4	
L E N G T H A N D W I D T H ²												
Cellulose acetate	+ 1.2	- 1.2	- 0.1	+ 1.2	- 1.2	+ 1.0	- 1.9	+ 0.2	+ 0.3	- 1.4	0.0	
Polystyrene	0.0	+ 0.1	0.0	+ 0.1	+ 0.2	0.0	- 0.2	- 0.2	0.0	- 0.1	0.0	
Zein	- 0.2	- 0.6	- 0.2	+ 0.6	- 1.6	+ 0.4	- 1.0	+ 1.2	- 0.6	- 1.6	- 0.4	
Urea-formaldehyde	- 0.1	- 3.1	- 0.2	+ 2.1	- 2.6	+ 0.6	- 5.1	- 0.1	+ 0.6	- 3.3	+ 0.8	
Hard rubber	+ 2.4	- 0.8	- 0.3	+ 0.4	- 1.4	+ 0.3	- 1.2	+ 2.0	- 0.2	- 1.8	- 0.4	
Low-density balsa, length	+ 0.3	- 0.3	+ 0.3	0.0	- 0.3	0.0	- 0.3	0.0	- 0.2	- 0.3	- 0.2	
width	+ 0.4	- 1.0	+ 0.3	+ 0.3	- 0.8	+ 1.4	- 1.3	0.0	0.0	- 1.0	+ 0.2	
Glass	0.0	+ 0.1	+ 0.1	0.0	0.0	+ 0.2	0.0	- 0.3	0.0	- 0.2	+ 0.1	
T H I C K N E S S ³												
Cellulose acetate	- 0.9	+ 0.9	0.0	+ 0.9	- 1.8	+ 0.9	- 1.8	0.0	+ 0.9	- 0.9	0.0	
Polystyrene	0.0	- 0.5	+ 0.5	- 0.5	0.0	0.0	0.0	+ 0.5	+ 0.5	- 0.5	0.0	
Zein	+ 1.8	+ 0.3	+ 0.3	+ 0.4	- 0.4	- 2.2	+ 1.0	- 1.0	- 2.6	- 2.2	- 0.7	
Urea-formaldehyde	- 1.3	- 3.0	0.0	+ 1.1	- 1.8	+ 0.7	- 5.0	- 0.6	- 0.7	- 1.6	+ 0.9	
Hard rubber	+ 3.0	- 1.0	- 0.5	+ 1.0	- 2.5	+ 0.5	- 2.5	+ 3.0	+ 0.5	- 3.5	- 0.5	
Low density balsa	+ 2.1	- 1.6	+ 1.6	0.0	- 1.6	+ 1.0	- 1.0	- 0.8	0.0	- 1.6	0.0	
Glass	- 0.5	+ 0.2	0.0	0.0	0.0	0.0	0.0	- 0.5	0.0	0.0	- 0.2	

¹Method 6011, Federal Specification L-P-408a. Two specimens of each material were tested. The same specimens were subjected to tests I to V, consecutively. The values in the table are average changes from the previous condition, calculated to percentage of the initial weight or dimensions of the conditioned specimen.

²Probable error in the values is of the order of ± 0.2 .

³Probable error in the values is of the order of ± 0.5 .

TABLE III.- CHANGES IN WEIGHT AND DIMENSIONS OF LOW-DENSITY
MATERIALS DURING 240-HOUR OVEN-FOG CYCLIC

ACCELERATED WEATHERING TEST

Material ¹	Change in weight (percent)	Change in length and width ² (percent)	Change in thickness ³ (percent)
Cellulose acetate	0.05	-1.0	-0.6
Polystyrene	-1.2	-.9	-.8
Zein	-2.1	-3.0	(4)
Hard rubber	-1.2	-1.4	-1.1
Low-density balsa	-.2	-1.0	2.2
Glass	-.4	-1.4	-1.6

¹Two specimens of each material were tested. The figures in the table are the average percentage changes, based on initial conditioned values.

²Probable error in the values is of the order of ± 0.2 .

³Probable error in the values is of the order of ± 0.5 .

⁴One specimen exhibited 1.1-percent increase, the other 1.1-percent decrease.

TABLE IV.- EFFECT ON LOW-DENSITY MATERIALS OF EXPOSURE
OUTDOORS FOR 7 MONTHS¹

Material	Changes in dimensions		Warp ²	Remarks on conditions after exposure
	Length-wise (percent)	Cross-wise (percent)	Length-wise (in.)	
Cellulose acetate	-10 to 10	-20	-----	Badly warped
Polystyrene	0	0	0.12	Eroded so that thickness is half of original, except where wire screen protected panel.
Zein	-13	-9	2.9	Underside soft near center, probably caused by absorption of condensed moisture.
Hard rubber	-2.5	-.8	.6	Surface dulled: slightly warped.
Balsa, low-density	0	-4	.04	Surface cracks in direction of grain.
Glass	0	0	0	Same as original.

¹Specimens exposed from March 15, 1944 to Oct. 17, 1944 on roof of Industrial Building, Nat. Bur. of Standards, Washington, D.C.: examined at 3:00 p.m. after 3 days of clear weather.

²Warp calculated to that for specimen 12 in. in length, assuming that warp varies with square of length of specimen. The lengths of the specimens varied from 9 to 18 in.

TABLE V.- CHANGES IN WEIGHT AND DIMENSIONS OF LOW-DENSITY MATERIALS¹
IMMERSED FOR 7 DAYS IN CHEMICALS AT 25° C

Chemicals	Change for cellulose acetate (percent)	Change for poly- styrene (percent)	Change for zein (percent)	Change for urea- formal- dehyde (percent)	Change for hard rubber (percent)	Change for low- density balsa (percent)	Change for glass (percent)
Weight							
Water	420	130	150	960	65	510	10
Ethyl alcohol, 95 percent	300	210	280	1440	52	590	7
Ethylene glycol	250	100	310	560	40	250	17
Glycerol	240	180	40	200	31	210	18
Diacetone		300	480	1570	79	320	16
alcohol	Dissolved						
Acetone	Dissolved	Dissolved	200	1170	100	820	5
Motor oil (SAE #10)	160	180	160	1780	55	190	14
Gasoline blend ²	180	Dissolved	130	1370	210	490	6
Heptane	170	64	150	1260	48	320	9
Length and Width ³						L	W
Water	2.4	-0.7	-0.8	2.0	0	0.7	2.8
Ethyl alcohol, 95 percent	5.8	.7	10.0	1.9	.6	.8	1.8
Ethylene glycol	6.2	1.4	5.4	-1.2	0	.8	2.6
Glycerol	-.2	0	-.8	-.8	.1	.7	.7
Diacetone		23.6	11.3	-1.8	-.2	.4	2.0
alcohol	Dissolved						
Acetone	Dissolved	Dissolved	-.4	-1.2	0	0	1.4
Motor oil (SAE #10)	-0.1	-1.0	-.4	.1	-.5	-.2	-.1
Gasoline blend ²	.2	Dissolved	-.2	3.0	2.1	0	.1
Heptane	-.7	-49.3	-.3	-.8	.6	-.3	-.3
Thickness ⁴							
Water	-1.0	-1.1	1.0	2.6	-0.8	1.4	-0.7
Ethyl alcohol, 95 percent	.4	.6	8.3	1.7	.6	3.2	.1
Ethylene glycol	-.7	-.4	6.0	-1.4	-.4	2.0	-.1
Glycerol	-1.4	1.2	-1.6	-.9	.6	2.4	0
Diacetone		20	13.9	-1.5	-.2	.9	-.1
alcohol	Dissolved						
Acetone	Dissolved	Dissolved	-.7	-1.6	0	1.3	-.5
Motor oil (SAE #10)	-0.6	-0.2	-2.1	.2	0	0	-.1
Gasoline blend ²	1.3	Dissolved	2.7	4.3	1.2	0	-.3
Heptane	-.7	-41.7	-.6	.3	-.4	-1.9	-.7

¹One specimen of each material was tested. The percentage change is based on the initial weight or dimensions of the conditioned specimen.

²The gasoline blend consisted of 80 percent 100 octane gasoline, 20 percent toluene, 15 percent xylene, and 5 percent benzene.

³Probable error in the values is of the order of ± 0.2 .

⁴Probable error in the values is of the order of ± 0.5 .

TABLE VI.- CHANGES IN WEIGHT AND DIMENSIONS OF LOW-DENSITY MATERIALS¹

IMMERSED FOR 7 DAYS IN CHEMICALS AT 25° C AND THEN

AIR-DRIED AT 25° TO 30° C FOR 7 DAYS

Chemicals	Change for cellulose acetate (percent)	Change for poly-styrene (percent)	Change for zein (percent)	Change for urea-formaldehyde (percent)	Change for hard rubber (percent)	Change for low-density balsa (percent)	Change for glass (percent)
Weight							
Water	0	0	28.7	-1.5	3.4	-4.0	-0.2
Ethyl alcohol, 95 percent	0	0	175	49.0	2.3	-9	-7
Ethylene glycol	211	34.7	196	458	6.0	294	15.2
Glycerol	190	147	28.2	130	28.2	188	11.1
Diacetone alcohol	Dissolved	1.0	228	280	16.6	40.0	-4
Acetone	Dissolved	Dissolved	-17.7	-3.0	7.8	-2.0	-7
Motor oil (SAE #10)	108	127	122	1258	53.6	200	13.1
Gasoline blend ²	8.4	Dissolved	28.0	31.0	7.4	87.0	-7
Heptane	-1.6	3.4	102	14.0	1.9	158	-2
Length and Width ³						L	W
Water	-0.4	-0.4	-1.2	-0.6	0.1	0.8	0
Ethyl alcohol, 95 percent	-2.3	-3	1.3	2.7	.3	.4	-4
Ethylene glycol	6.4	-2	2.0	3.6	-2	.7	2.7
Glycerol	-2	-2	-5	-8	.1	.9	1.0
Diacetone alcohol	Dissolved	-2	7.1	-8	0	.4	2.2
Acetone	Dissolved	Dissolved	-8.5	-1.7	-9	.1	-2.1
Motor oil (SAE #10)	-0.1	0	-0.8	0.4	-5	0	-2
Gasoline blend ²	.2	Dissolved	-4	.2	-7	0	-3
Heptane	-3	-50.3	-4	-1.3	.5	.4	.7
Thickness ⁴							
Water	0.4	0	1.6	-0.9	0.4	1.8	-0.4
Ethyl alcohol, 95 percent	-1.4	-7	2.4	3.0	.2	2.1	-4
Ethylene glycol	-2.0	-2	3.0	-1.5	.4	1.4	-3
Glycerol	-4	0	-1.7	-4	0	2.2	-1
Diacetone alcohol	Dissolved	-6	9.8	-6	0	.5	-1
Acetone	Dissolved	Dissolved	-8.3	-1.7	.4	1.3	-4
Motor oil (SAE #10)	-0.3	0	-2.5	0	-2	-4	-1
Gasoline blend ²	-2.4	Dissolved	2.6	.4	-2.0	-2	-2
Heptane	-2.9	-44.1	-9	-1.0	.8	-1.5	.1

¹One specimen of each material was tested. The percentage change is based on the initial weight or dimensions of the conditioned specimen.

²The gasoline blend consisted of 80 percent 100-octane gasoline, 20 percent toluene, 15 percent xylene, and 5 percent benzene.

³Probable error in the values is of the order of ± 0.2 .

⁴Probable error in the values is of the order of ± 0.5 .

TABLE VII.- WATER ABSORPTION¹ OF LOW-DENSITY MATERIALS

Material ²	Change after 24-hr immersion at 77° F (percent)	Change after 24-hr drying at 122° F (percent)	Total change from initial condition (percent)
Weight			
Cellulose acetate	201	-200	1
Polystyrene	78	-77	1
Zein	163	-99	64
Urea-formaldehyde	399	-397	2
Hard rubber	27.1	-27.5	-.4
Balsa, low-density	203	-202	1
Glass	139	-139	0
Length and Width ³			
Cellulose acetate	2.9	-2.7	0.2
Polystyrene	-.2	-.2	-.4
Zein	1.5	-.4	1.1
Urea-formaldehyde	4.6	-4.8	-.2
Hard rubber	.1	-.3	-.2
Balsa, low-density			
(length	1.0	-.4	.6
(width	3.5	-3.0	.5
Glass	-.1	-.2	-.3
Thickness ⁴			
Cellulose acetate	0.7	-0.3	0.4
Polystyrene	-.3	-.6	-.9
Zein	4.0	-1.1	2.9
Urea-formaldehyde	4.4	-4.9	-.5
Hard rubber	.4	-.2	.2
Balsa, low-density	2.7	-3.9	-1.2
Glass	-.1	-.1	-.2

¹Procedure same as Method 7031, Federal Specification L-P-406a (reference 3).

²One specimen of each material was tested. The percentage change is based on the initial weight or dimensions of the conditioned specimen.

³Probable error in the values is of the order of ± 0.2 .

⁴Probable error in the values is of the order of ± 0.5 .

TABLE VIII.- SOFTNESS INDEX FOR SAMPLES IMMERSSED IN VARIOUS CHEMICALS

Material	Measurement Made	Softness Index ¹ before and after Immersion in the Indicated Chemical for the Length (L), Width (W), and Thickness (T) of the Specimens																					
		Water		Ethyl Alcohol, 95%		Ethylene Glycol		Glycerol		Diacetone Alcohol		Acetone		Motor Oil (SAE #10)		Gasoline Blend		Heptane					
		L	W	T	L	W	T	L	W	T	L	W	T	L	W	T	L	W	T				
Cellulose acetate do. do.	Before immersion	2.0	0.6		1.0	0.8		1.2	1.2		1.4	0.8	—	—		0.6	0.7		0.9	0.6		0.7	0.2
	After 7 days immersion	1.8	1.0		1.7	0.8		1.3	1.0		1.5	0.5	Dissolved	Dissolved		0.7	0.5		1.0	0.6		0.6	0.8
	After 7 days air drying	1.2	0.5		1.0	0.4		1.4	0.6		1.4	0.6	—	—		1.0	0.7		0.9	1.8		1.1	0.4
Polystyrene do. do.	Before immersion	0.6	0.8		0.8	0.7		0.6	0.8		0.7	0.7	0.4	0.6		0.6	0.6		—	—		0.8	0.6
	After 7 days immersion	0.8	0.2		0.8	0.6		0.8	0.8		1.2	1.2	1.6	0.6		0.6	0.4		Dissolved	Dissolved		1.2	1.0
	After 7 days air drying	0.6	0.8		0.6	0.2		0.6	0.6		0.6	0.4	0.6	0.7		0.7	0.8		—	—		1.7	0.2
Zein do. do.	Before immersion	0.3	0.4		0.3	0.3		0.4	0.3		0.5	0.3	0.4	0.3		0.3	0.6		0.4	0.3		0.4	0.4
	After 7 days immersion	4.4	9.4		12.2	17.3		11.9	15.1		0.4	0.3	5.1	4.1		1.2	0.6		0.3	0.4		0.4	0.1
	After 7 days air drying	0.6	1.0		0.4	0.4		14.4	17.5		0.5	0.2	3.0	4.8		0.3	0.4		0.2	0.3		0.6	0.4
Urea-formaldehyde do. do.	Before immersion	1.2	1.2		0.8	0.7		1.1	1.2		1.1	0.8	1.0	1.1		1.4	2.9		1.0	1.4		0.8	0.8
	After 7 days immersion	2.1	1.8		1.0	1.0		1.0	0.8		1.0	1.1	0.8	0.8		1.6	3.9		0.9	0.8		0.8	1.6
	After 7 days air drying	1.8	1.3		0.8	0.8		1.2	1.0		1.0	1.2	0.8	1.0		1.0	1.5		0.8	0.9		1.4	1.8
Hard rubber do. do.	Before immersion	0.7	0.1		0.4	0.2		0.6	0.4		0.4	0.2	0.6	0.2		0.3	0.4		0.7	0.2		0.4	0.4
	After 7 days immersion	0.4	0.2		0.4	0.2		0.6	0.4		0.5	0.2	0.6	0.3		1.9	2.1		0.4	0.2		0.8	0.6
	After 7 days air drying	0.4	0.2		0.4	0.4		0.5	0.6		0.6	0.2	0.5	0.4		1.1	0.6		0.6	0.2		0.8	1.0
Low-density balsa do. do.	Before immersion	0.4	0.3		0.3	0.2		0.2	0.1		0.2	0.2	0.2	0.2		0.3	0.2		0.4	0.2		0.2	0.3
	After 7 days immersion	0.4	0.2		0.4	0.4		0.4	0.6		0.3	0.2	0.4	0.0		0.5	0.2		0.2	0.2		0.3	0.0
	After 7 days air drying	0.2	0.2		0.4	0.4		0.4	0.0		0.2	0.2	0.3	0.6		0.4	0.2		0.4	0.2		0.4	0.4
Glass do.	Before immersion	0.4	0.2		0.1	0.0		0.2	0.2		0.1	0.1	0.2	0.1		0.1	0.2		0.2	0.2		0.2	0.2
	After 7 days immersion	0.2	0.1		0.2	0.2		0.2	0.2		0.2	0.0	0.1	0.0		0.2	0.1		0.3	0.2		0.0	0.1
	After 7 days air drying	0.4	0.1		0.1	0.2		0.1	0.0		0.2	0.4	0.2	0.2		0.1	0.2		0.2	0.1		0.2	0.2

¹Softness index is defined as the difference in the dimensions of the specimen in hundredths of an inch as measured on the Schiefer compressometer for forces of 0.1 and 1 pound, respectively; the higher the number, the softer the material. The values shown in the columns for length and width are the averages for the measurements in the two directions.

TABLE IX.- FLEXURE PROPERTIES¹ OF LOW-DENSITY MATERIALS

Material	Specimen Direction	Density, d (g/cm ³)	No. of Specimens	Effective Flexural Modulus of Elasticity, E_f		Modulus of Rupture, S_r		Span-Depth Ratio	Pads Used at Supports ²	Specific Flexure Values	
				Average (lb/in ²)	Range (lb/in ²)	Average (lb/in ²)	Range (lb/in ²)			$\frac{E_f}{d^2}$	$\frac{S_r}{d^3}$
Cellulose acetate	Lengthwise	0.085 ³	2	400	400	30	30	7	None	700,000	4,000
	Crosswise	0.085 ³	2	200	200	15	10-20	7	None	300,000	2,000
Polystyrene	Lengthwise	0.019 ³	2	900	800-1,000	25	22-25	7	None	130,000,000	70,000
	Crosswise	0.019 ³	2	1,300	1,300-1,400	35	30-35	7	None	190,000,000	100,000
	Lengthwise ⁴	0.0182	2	1,400	900-1,800	40	30-45	7	M	230,000,000	120,000
Zein	Lengthwise	0.157	2	2,600	2,500-2,700	60	55-60	7	None	670,000	2,400
	Crosswise	0.167	2	2,400	2,200-2,600	60	55-65	7	None	520,000	2,200
Hard rubber	Lengthwise	0.076	2	5,400	5,200-5,700	100	100	7	None	12,000,000	17,000
	Crosswise	0.075	2	5,800	5,500-6,100	85	75-95	7	None	14,000,000	15,000
	Lengthwise ⁵	0.074	2	5,000	4,400-5,700	85	85	7	M	12,000,000	16,000
Low-density balsa	Lengthwise	0.078	2	—	—	810	780-840	7 ⁶	None	—	130,000
	Lengthwise	0.068	2	—	—	700	670-720	16 ⁶	P	—	150,000
	Lengthwise	0.093	3	195,000	184,000-210,000	—	—	7	M	240,000,000	—
High-density balsa	Lengthwise	0.17 ⁷	3	—	—	2,950	2,150-4,060	7 ⁶	P	—	100,000
	Lengthwise	0.20 ⁸	3	—	—	4,480	3,480-6,090	16 ⁶	P	—	110,000
	Lengthwise	0.28	2	680,000	640,000-720,000	5,260	4,960-5,550	7	M	31,000,000	67,000
Glass	Lengthwise	0.16 ³	2	—	—	105	100-110	7	P	—	4,100

¹ Midspan loading; head motion adjusted to produce 0.006 to 0.012 in./in./min. strain rate for extreme fibers at midspan.

² P = 2 by 1 by 1/4 in. plywood block; M = 2 by 1 by 1/4 in. methyl methacrylate resin.

³ Density of compression test specimen.

⁴ Specimens taken from two different blocks of material.

⁵ Specimens taken from a different block of material than others.

⁶ Strain rate 0.002 in./in./min.

⁷ Range 0.14 to 0.22.

⁸ Range 0.16 to 0.27.

TABLE X.- FLATWISE COMPRESSION DATA FOR LOW-DENSITY MATERIALS

Material	Density average (g/cm ³)	Number of speci- mens ¹	Effective compressive modulus of elasticity ²		Spherical head used	Rate of head motion (in./min)
			Average (lb/in. ²)	Range (lb/in. ²)		
Cellulose acetate	0.089	3	3400	3300 to 3500	Yes	0.05
	.088	6	3300	2400 to 4400	No	.05
Polystyrene	.0183	3	300	280 to 310	Yes	.1
	.0190	5	480	410 to 560	No	.1
Zein	.169	3	570	500 to 640	Yes	.1
	.180	2	470	260 to 680	No	.1
Urea- formaldehyde	.037	1	30		Yes	.2
Hard rubber	.071	3	400	360-460	Yes	.1
	.072	2	540	370-710	No	.1
Balsa, low-density	.070	3	1400	1200 to 1600	Yes	.05
	.077	2	1500	1300 to 1700	No	
Balsa, high-density	.17	3	15,000	12,000 to 18,000	Yes	.05
	.22	3	34,000	27,000 to 38,000	No	.05
Glass	.165	3	ca. 5000		No	.05

¹Specimens were 3 by 3 in. by the thickness of the sheet except for the balsa specimens, which were 1 in. thick with planed faces.

²Based on compressive deformation as indicated by change in distance between the top and bottom bearing blocks. The slope of the straight portion of the graph was used to obtain the modulus.

TABLE XI.-- EDGEWISE COMPRESSION DATA FOR LOW-DENSITY MATERIALS

Material	Direction of Loading	Density, Average (g/cm ³)	No. of Specimens ¹	Effective Compressive Modulus of Elasticity ²		Compressive Yield Stress		Spherical Head Used	Rate of Head Motion (in./min.)	Specimen Height (in.)
				Average (lb/in ²)	Range (lb/in ²)	Average (lb/in ²)	Range (lb/in ²)			
Cellulose acetate do.	Lengthwise	0.084	3	350	250-500	ca. 10 to 20 ³		No	0.1	1
	Crosswise	0.079	3	350	250-500	ca. 10 to 20 ³		No	0.1	1
Polystyrene do.	Lengthwise	0.019	3	740	700-790	17	16-17	No	0.2	2
	Crosswise	0.019	3	820	730-950	16	14-18	No	0.2	2
Zein	Lengthwise	0.016	2	790	660-920	35	32-37	Yes	0.1	3
Hard rubber do.	Lengthwise	0.081	2	3,600	3,400-3,900	52	51-54	No	0.2	2
	Crosswise	0.079	3	4,200	3,900-4,500	50	46-52	No	0.2	2
Low-density balsa do.	Lengthwise	0.077 ⁴	3	95,000	68,000-138,000	760	500-950	Yes	0.05	2
	do.	0.075	2	140,000	133,000-146,000	670	530-810	No	0.05	2
	Crosswise do.	0.089	3	4,500	3,500-5,700	60 ⁵	48-75	Yes	0.05	2
		0.073	3	3,000	2,400-3,500	40 ⁵	37-46	No	0.05	2
High density balsa do.	Lengthwise	0.26	2			3,300	3,200-3,500	No	0.05	2
	do.	0.32	4	750,000 ⁷	690,000-810,000	4,700	4,400-4,900	Two with Two without)	0.003-0.008	2
do. do.	Crosswise	0.21 ⁶	3	20,000	12,000-32,000	220 ⁵	150-300	Yes	0.05	2
	do.	0.18 ⁶	3	20,000	14,000-27,000	180 ⁵	140-250	No	0.05	2

¹Specimens were geometrically similar with height and width each equal to twice the thickness.

²Based on compressive deformation as indicated by change in distance between top and bottom bearing blocks. The slope of the straight portion of the graph was used to obtain the modulus.

³Stress-strain diagram does not become quite horizontal, so these values are not yield stress in the ideal sense.

⁴Range 0.067 to 0.089

⁵Range 0.17 to 0.27

⁶Range 0.16 to 0.22

⁷Dial gages graduated to 0.0001 inch used for indicating distance between bearing blocks in this test.

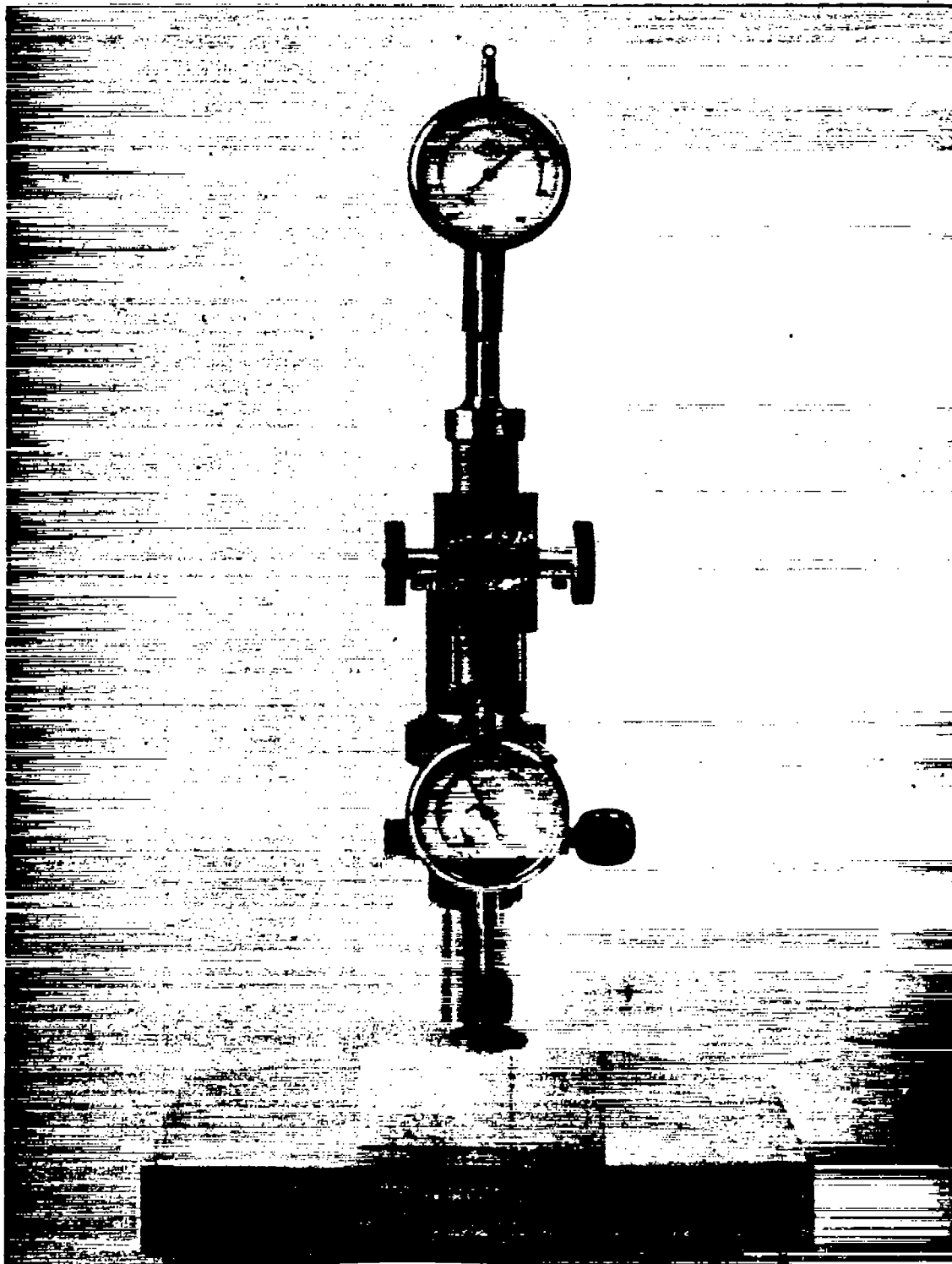


Figure 1.- Schiefer compressometer used for measuring dimensions of low-density materials. Specimen is polystyrene.



Figure 2.- Flexure jig in place in testing machine. Low-magnification extensometer, Model PS-7, is attached.

Fig. 2

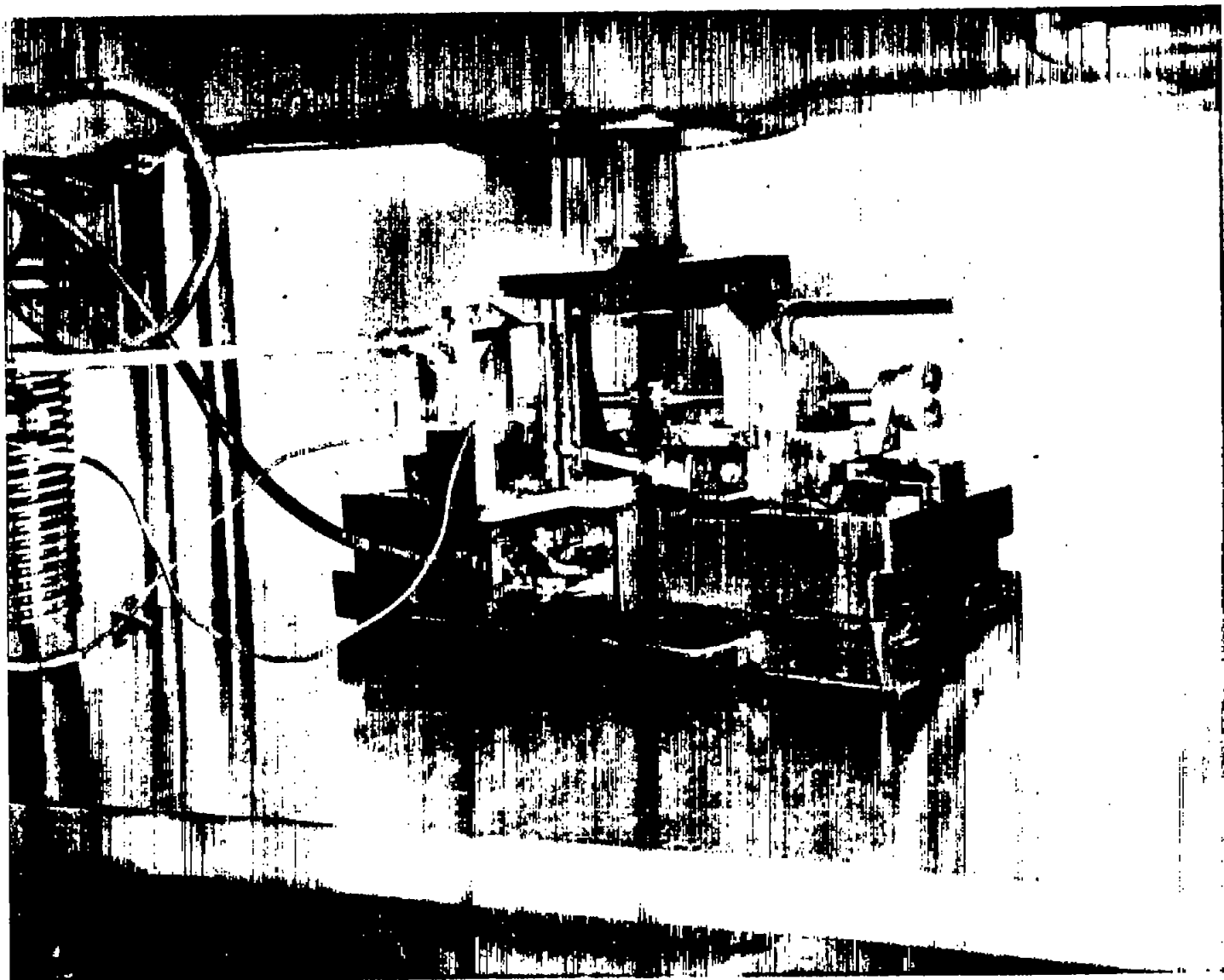


Figure 3.- Flexure specimen of hard rubber in place ready for testing.

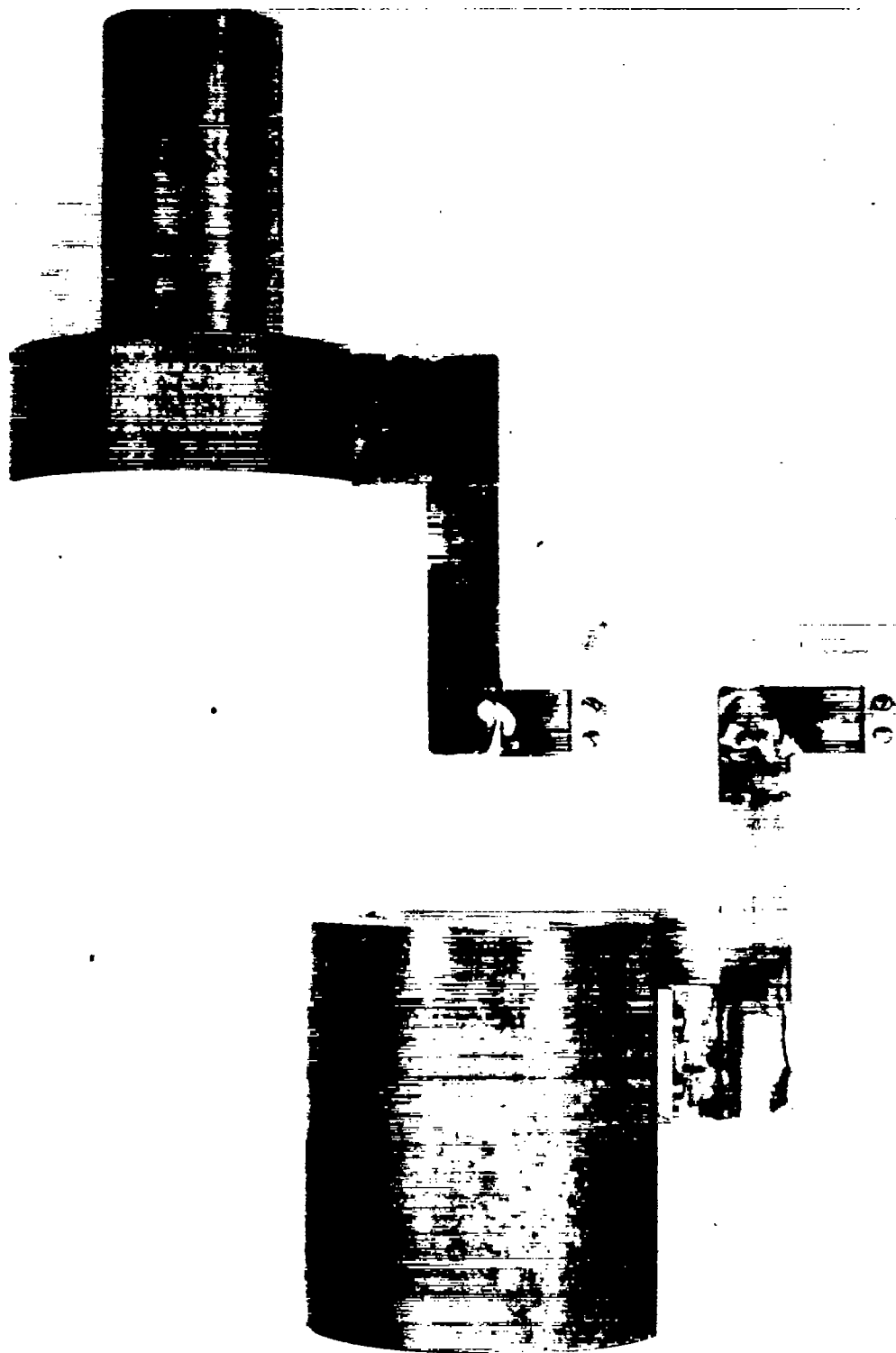


Figure 4.- Compression test bearing blocks equipped with brackets to which Southwark-Peters plastics extensometer can be attached.

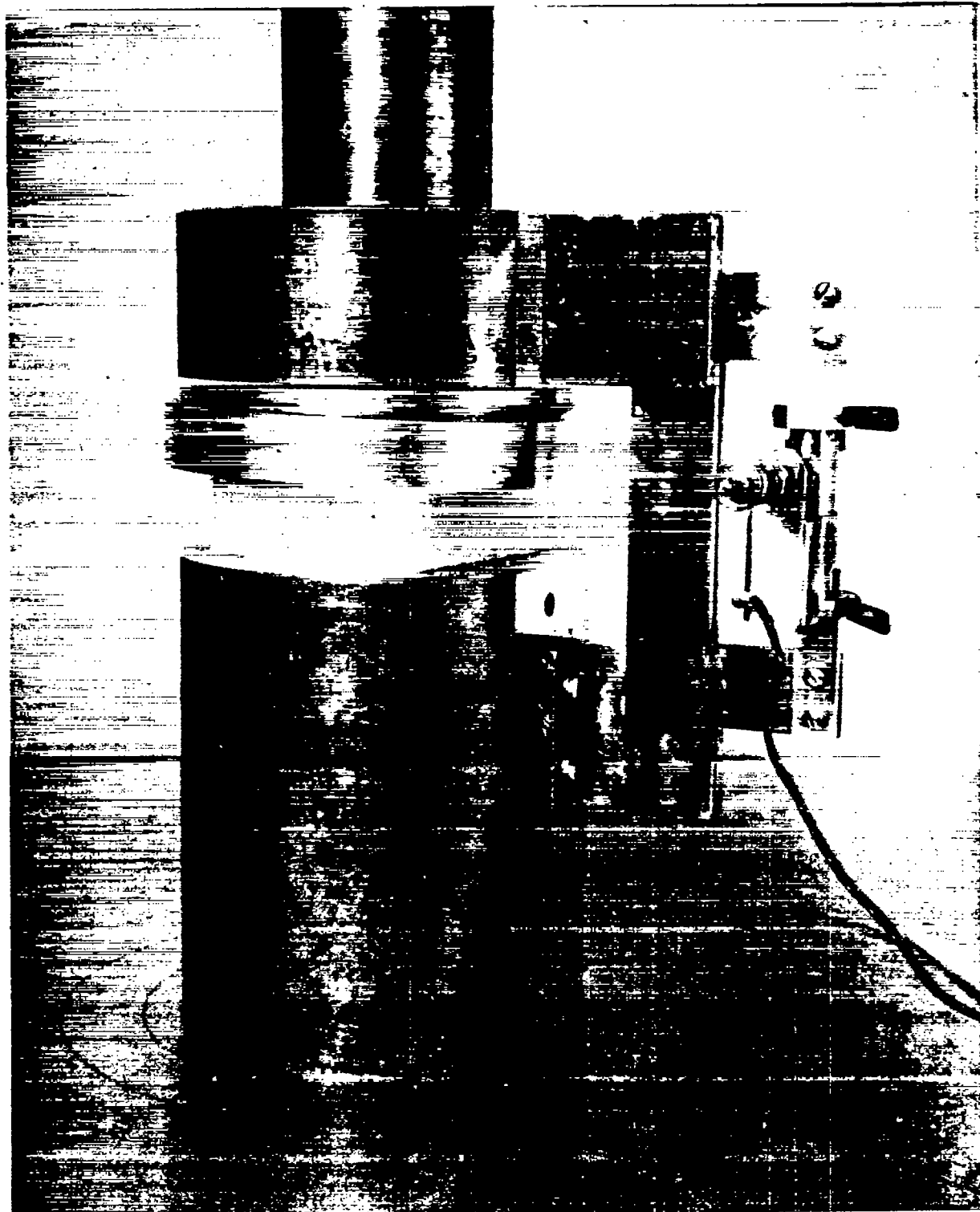


Figure 5.- Specimen of polystyrene in place for flatwise compression test. Aluminum alloy spherical bearing head on top of specimen.

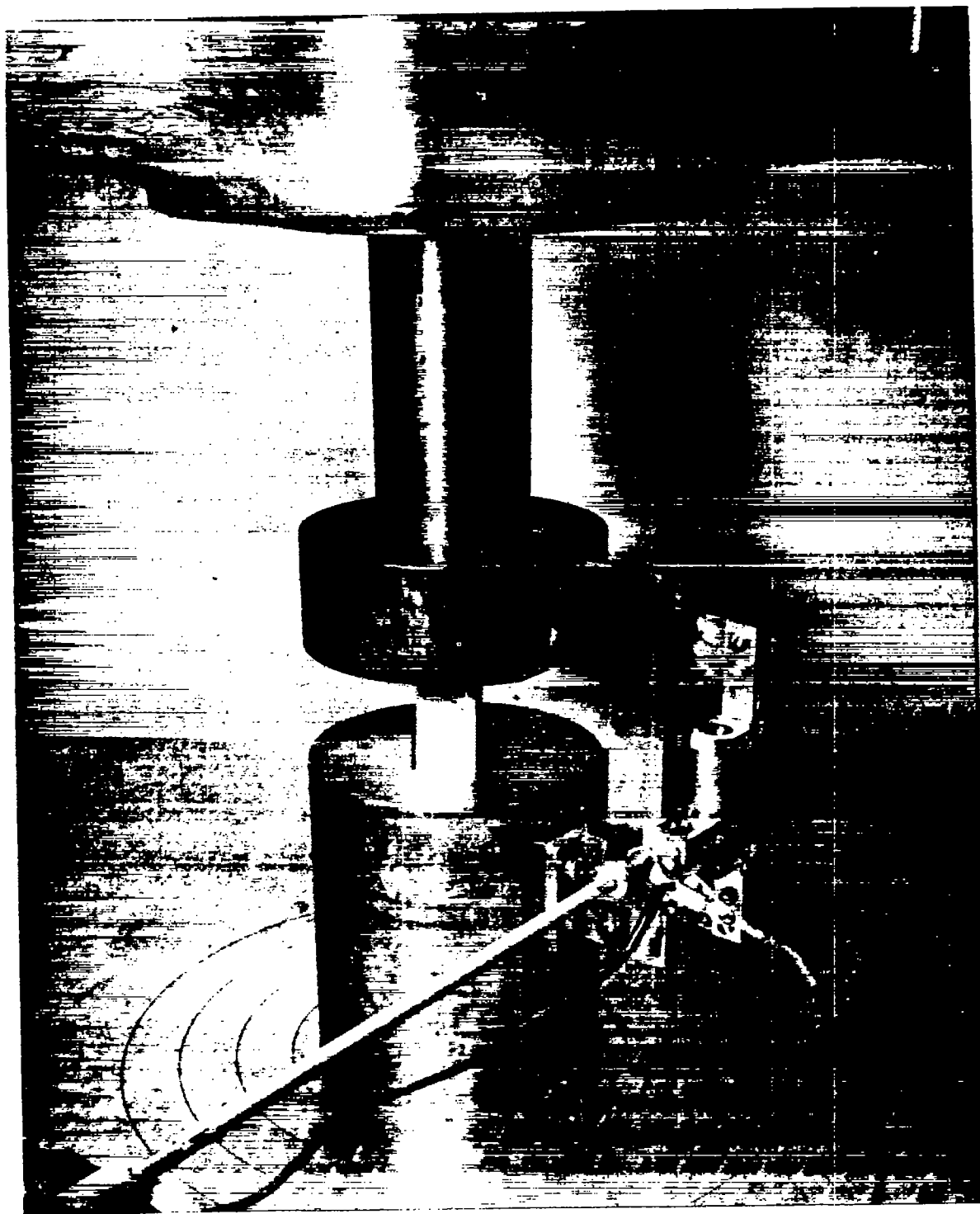


Figure 6.- Specimen of balsa wood in place for edgewise compression test. High magnification extensometer, Model PS-6, is attached.

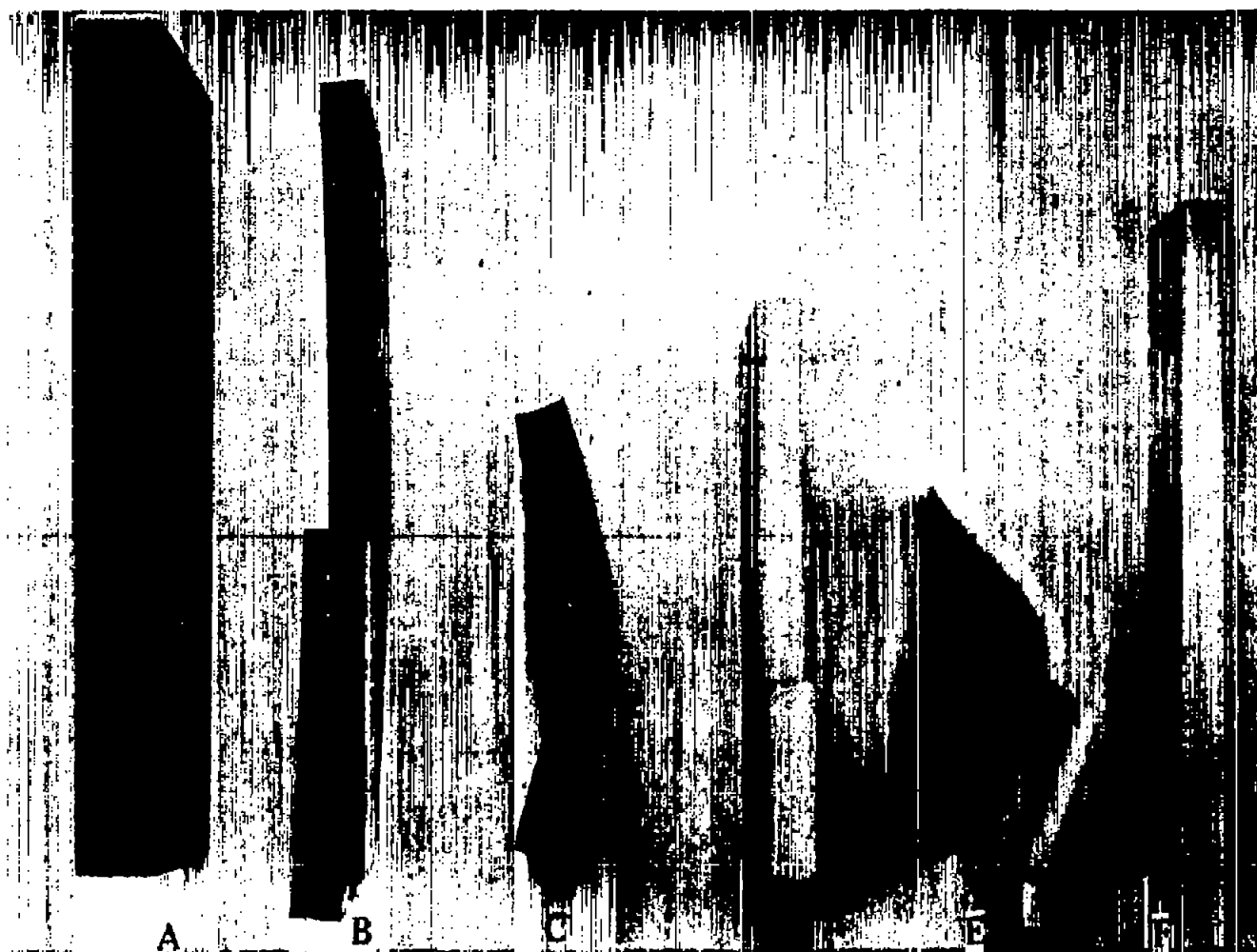
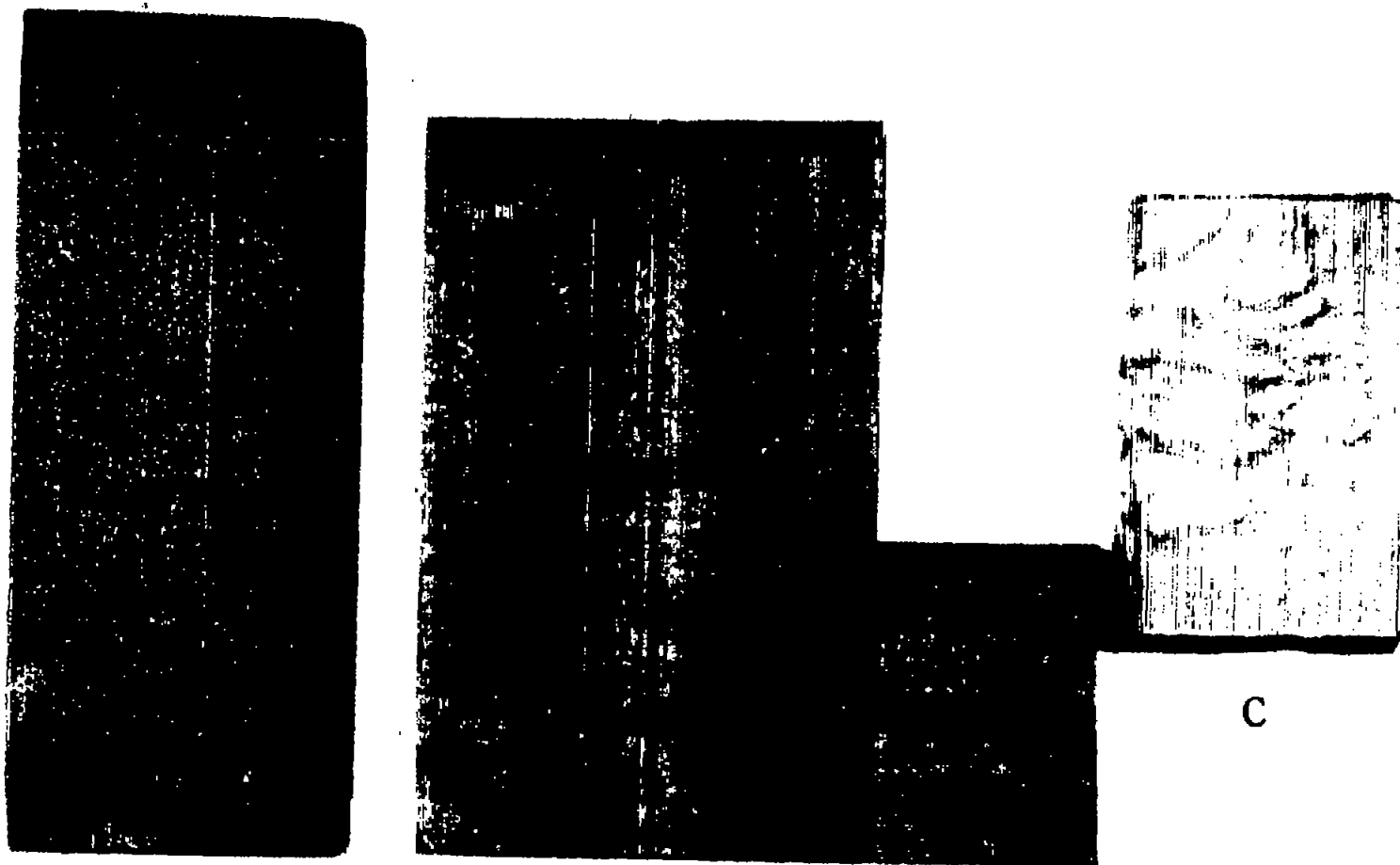


Figure 7 (a to c).- Samples of low-density materials after 3 months outdoor exposure, March 15 to May 15, 1944, in Washington, D.C. A, glass; B, hard rubber; C, zein; D, polystyrene; E, cellulose acetate; F, low-density balsa.



B

C

Figure 7.- (Continued).

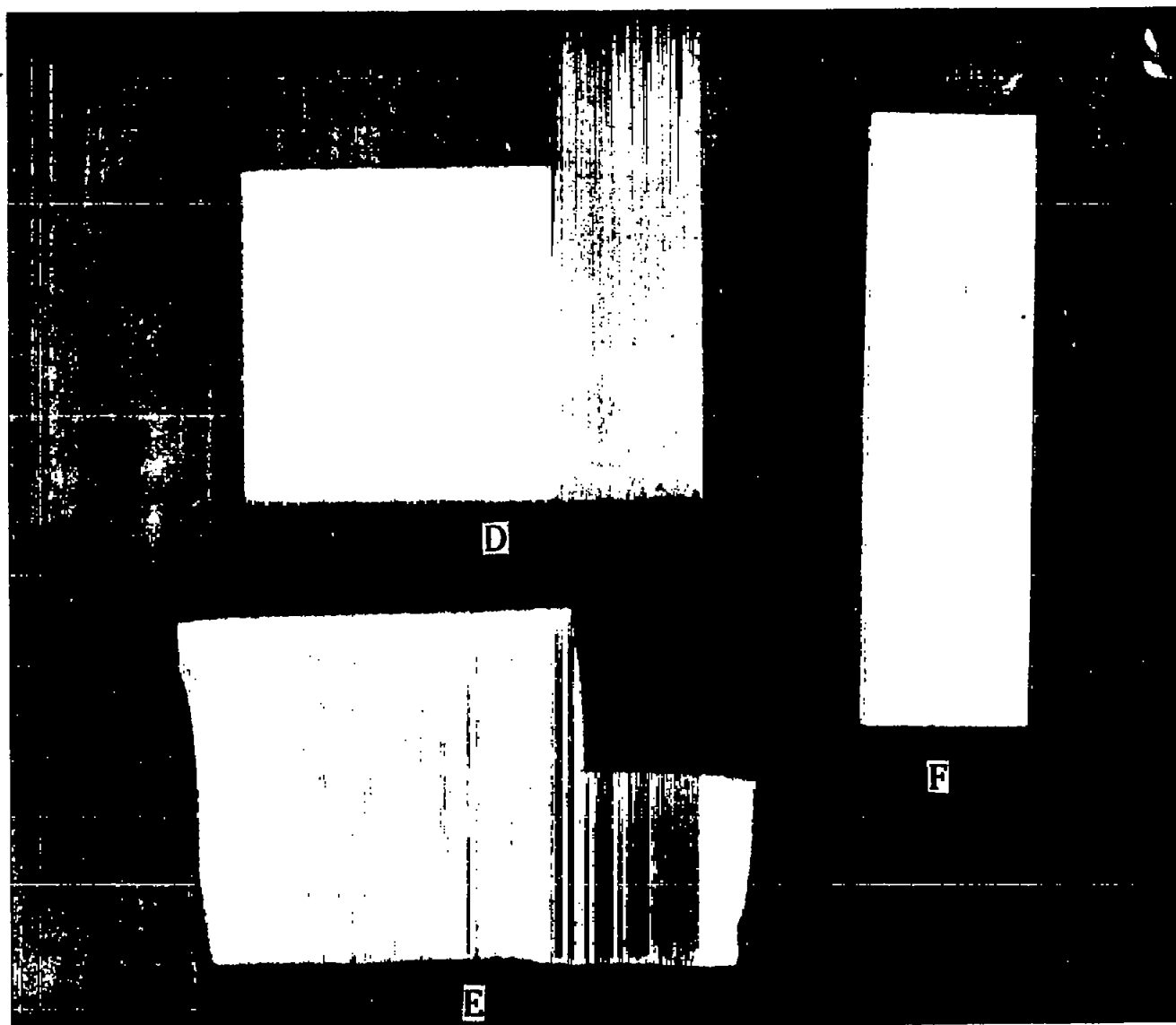


Figure 7.- (Concluded).

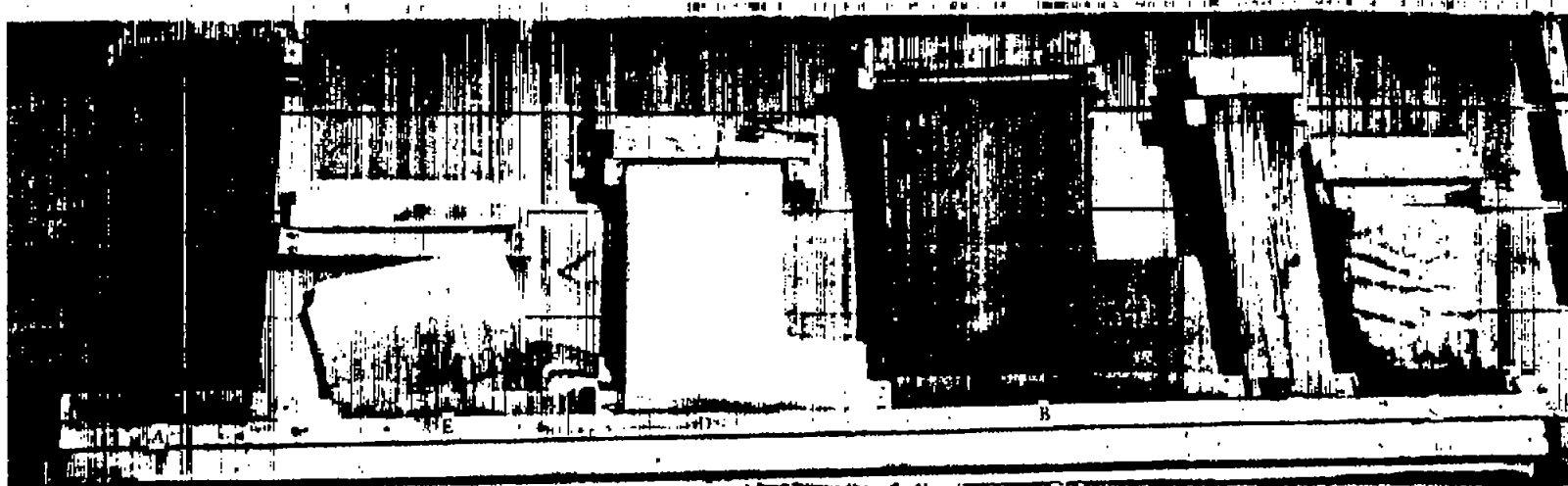


Figure 8a,b.- Samples of low-density materials after 7 months outdoor exposure, March 15 to October 14, 1944, in Washington, D.C. A, glass; B, hard rubber; C, zein; D, polystyrene; E, cellulose acetate; F, low-density balsa.

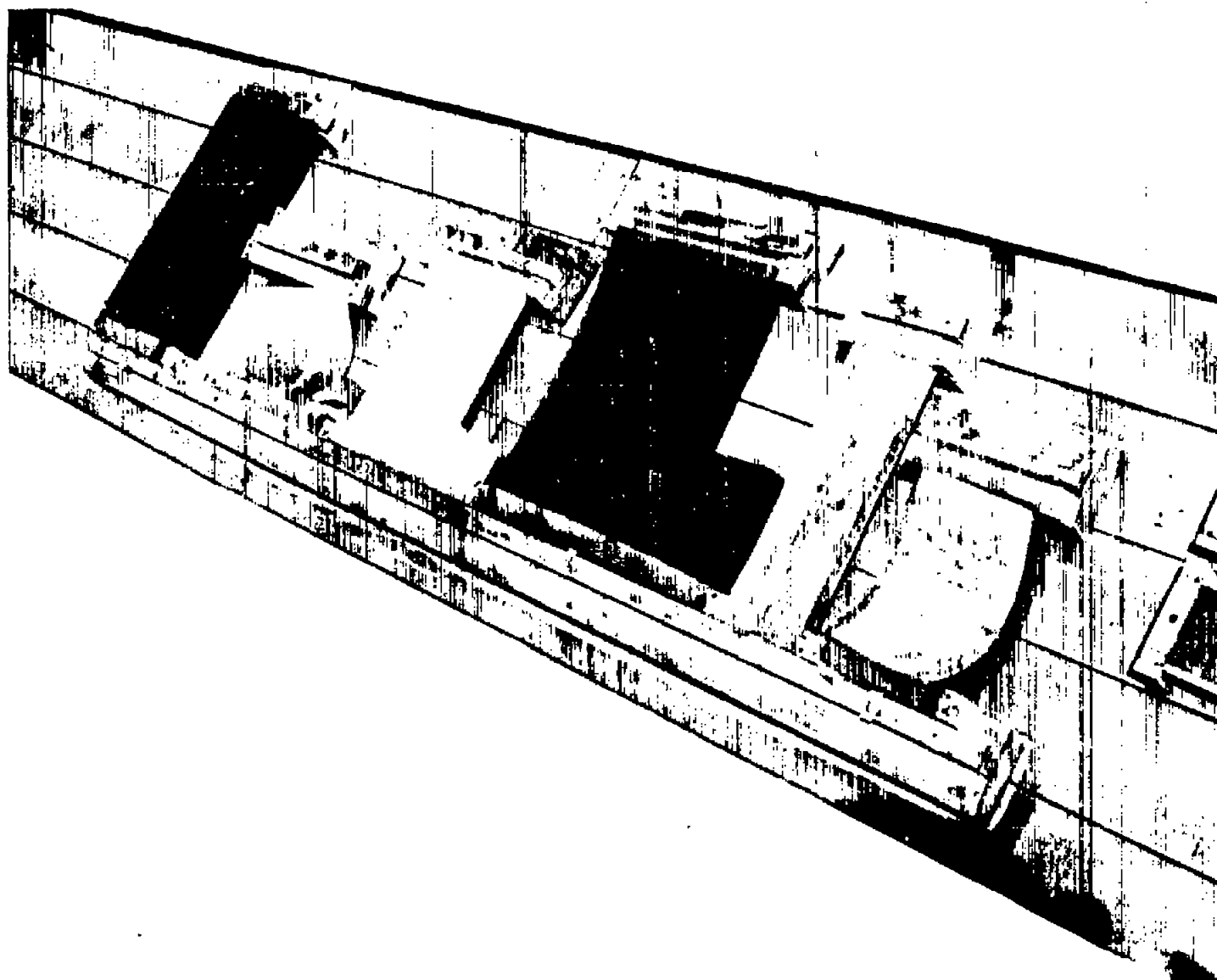


Figure 8.- (Concluded).

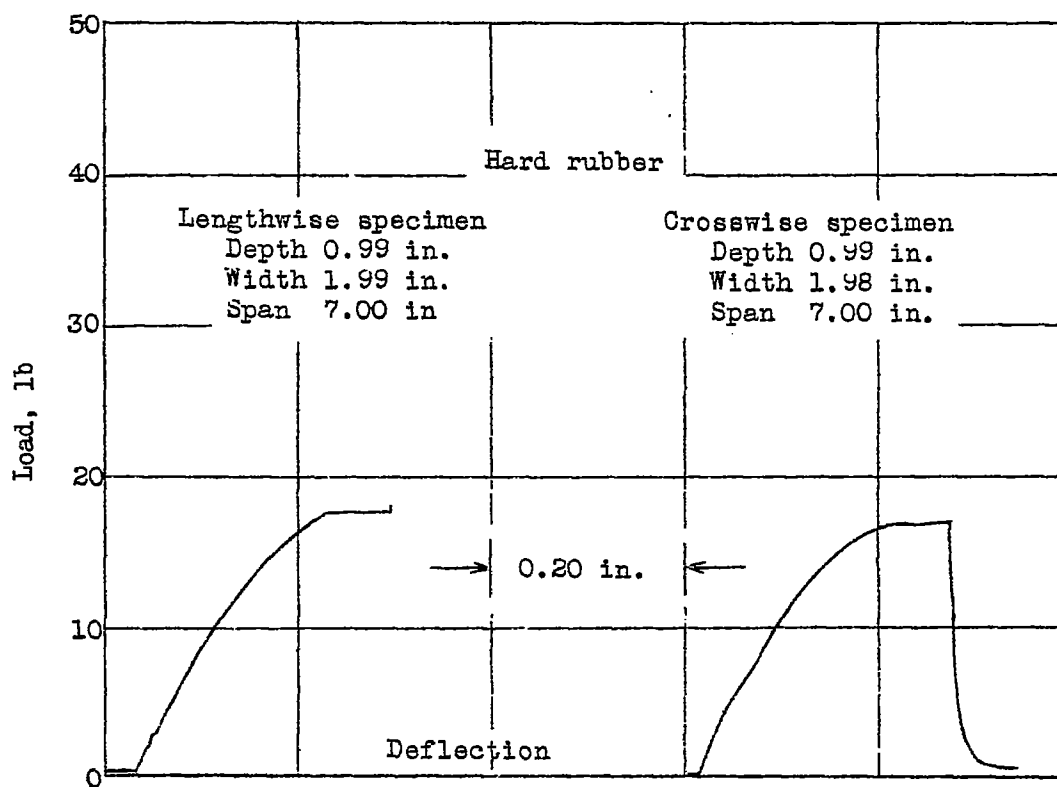


Figure 9.- Typical flexure load-deflection curves obtained with an automatic recorder.

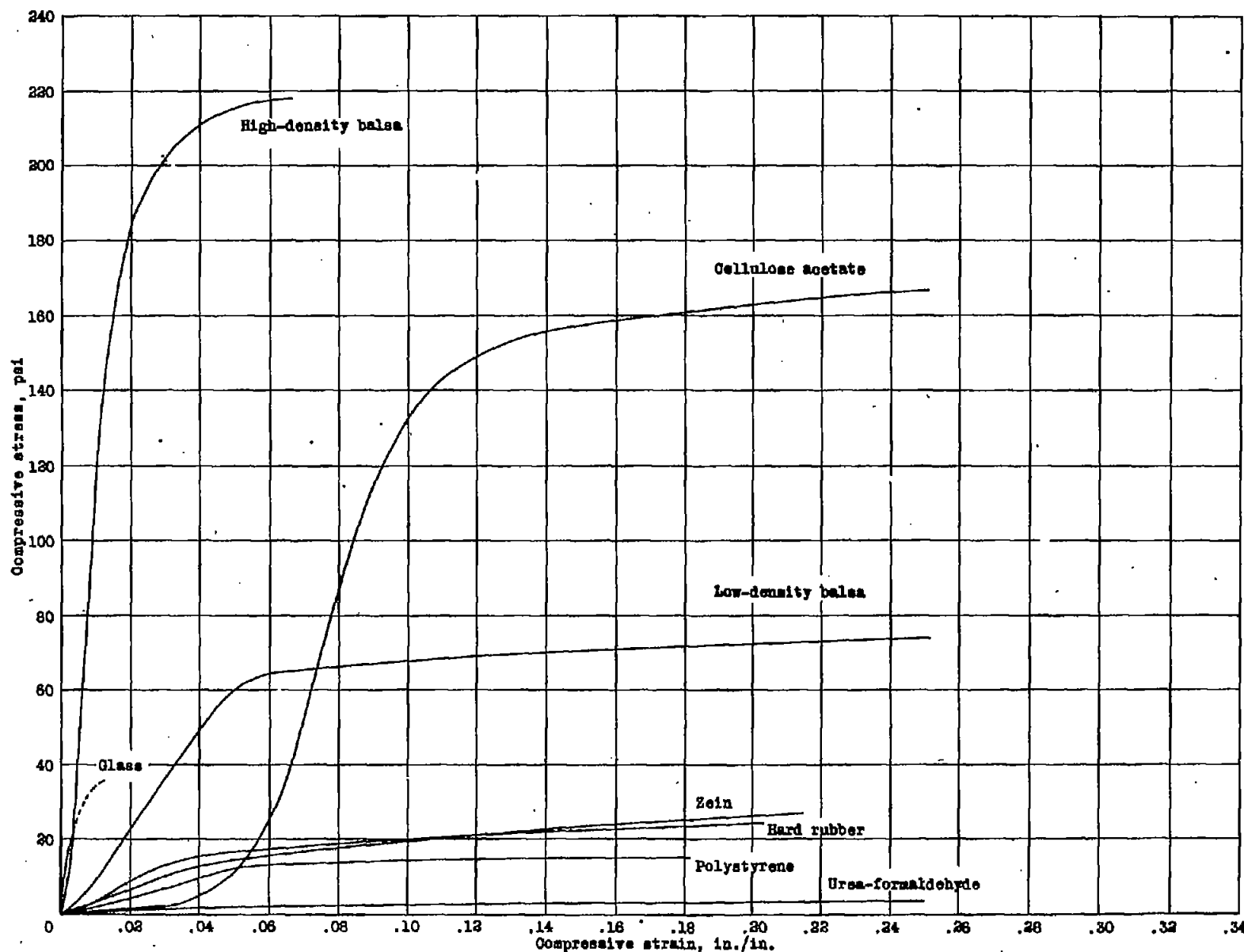


Figure 10.- Average flatwise compressive stress-strain curves for low-density materials.

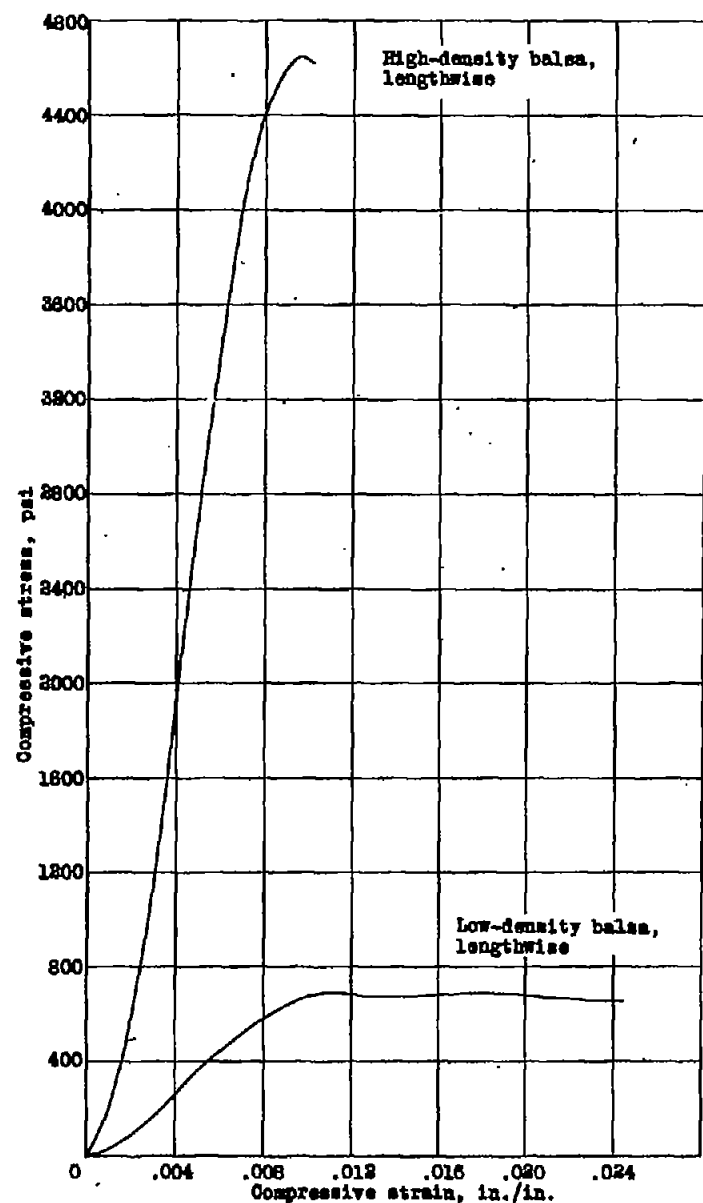
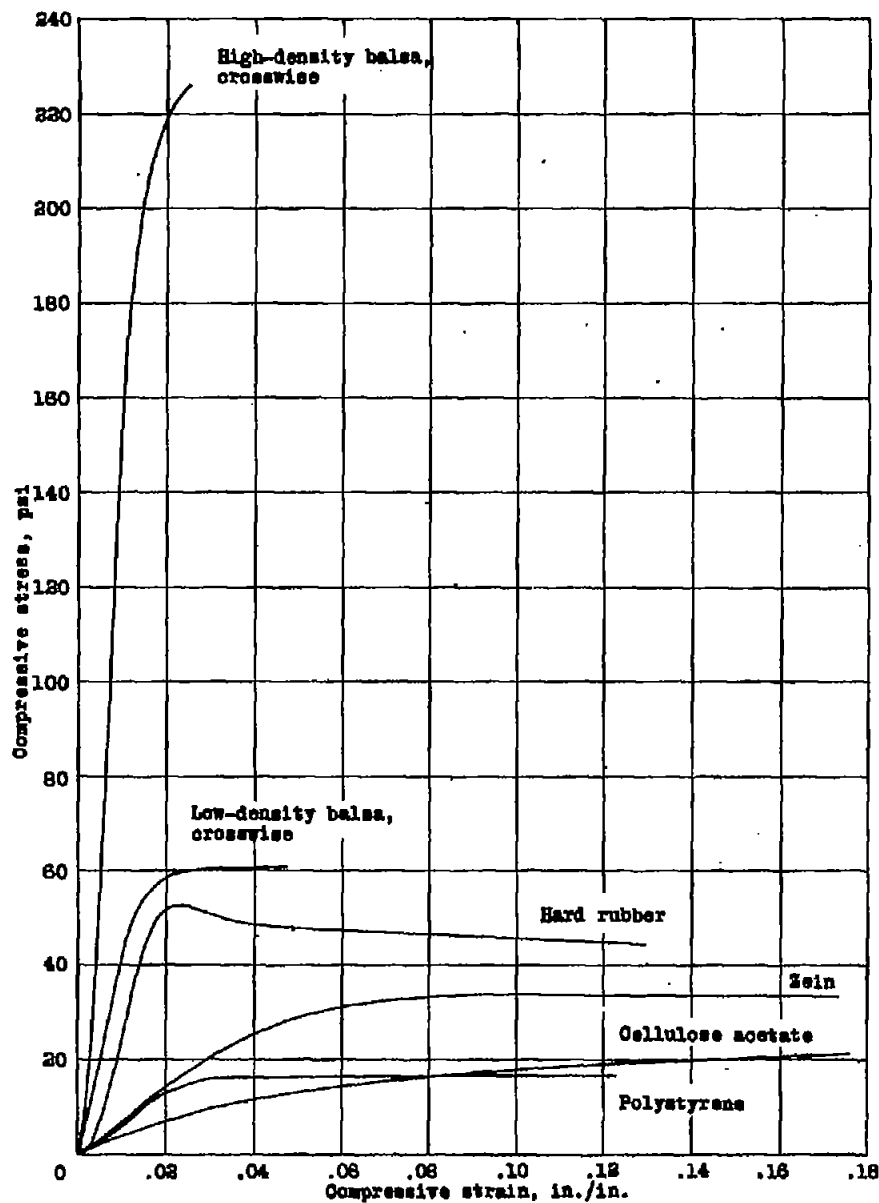


Figure 11.- Average edgewise compressive stress-strain curves for low-density materials.

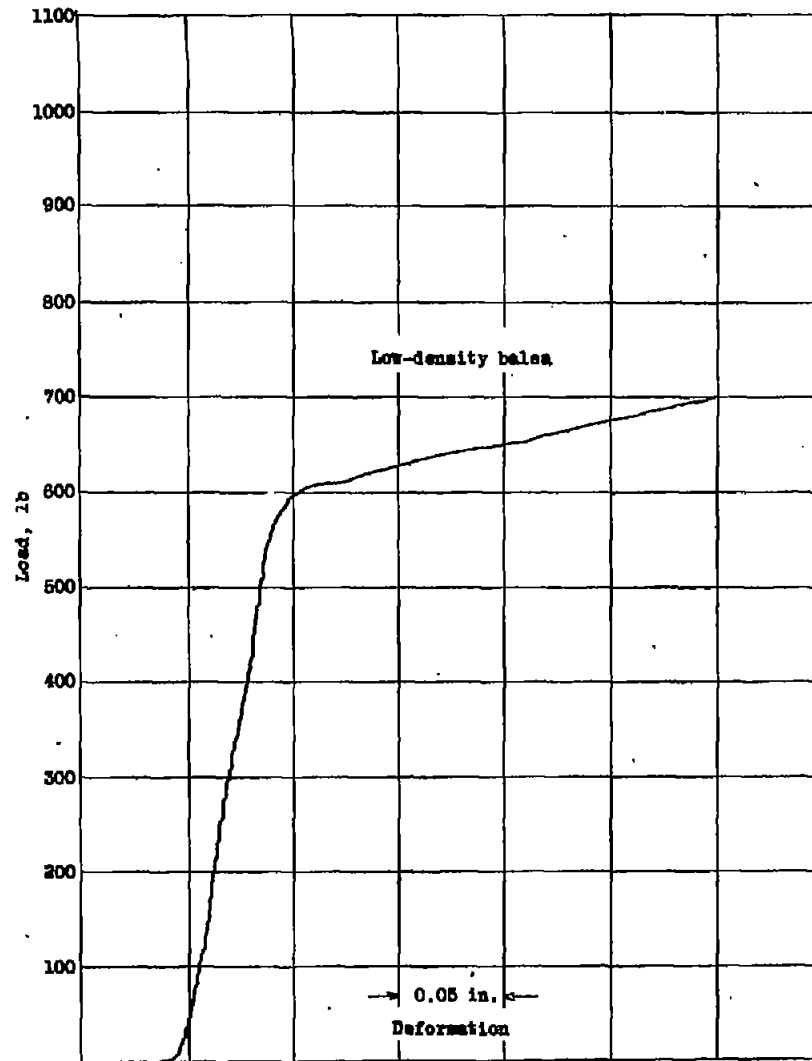
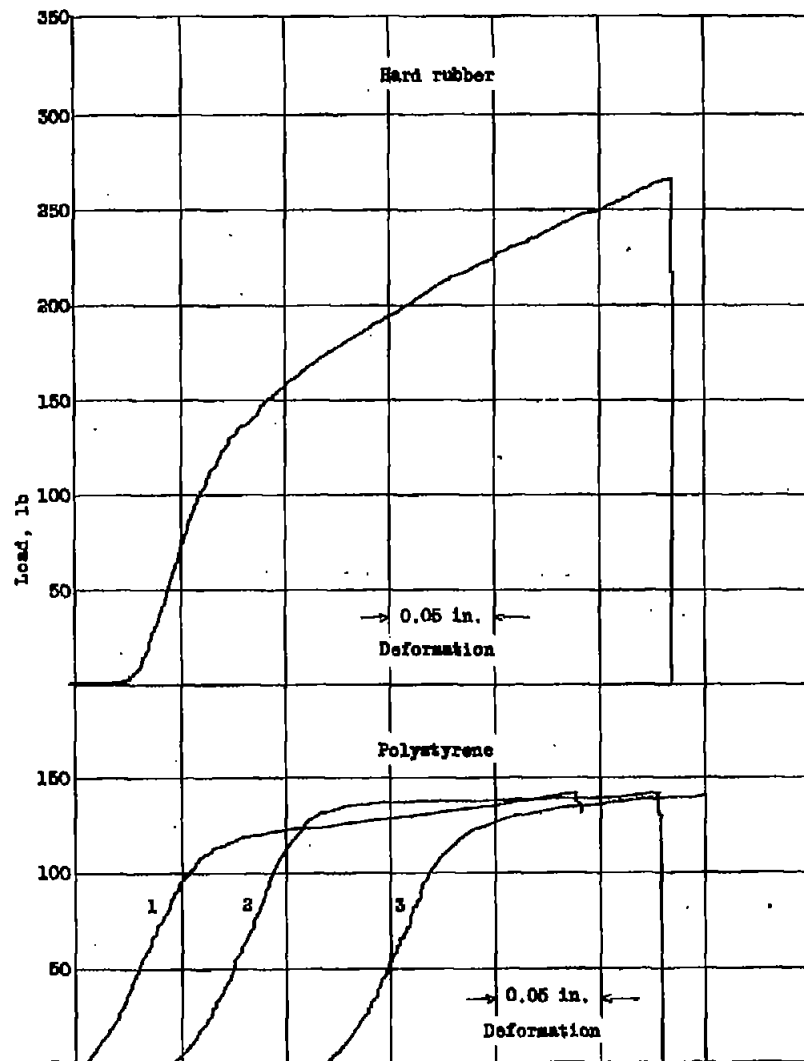


Figure 12.- Typical flatwise-compression load-deformation curves obtained with an automatic recorder. Specimens 3-by 3-by 1-inch were tested using a spherical head.

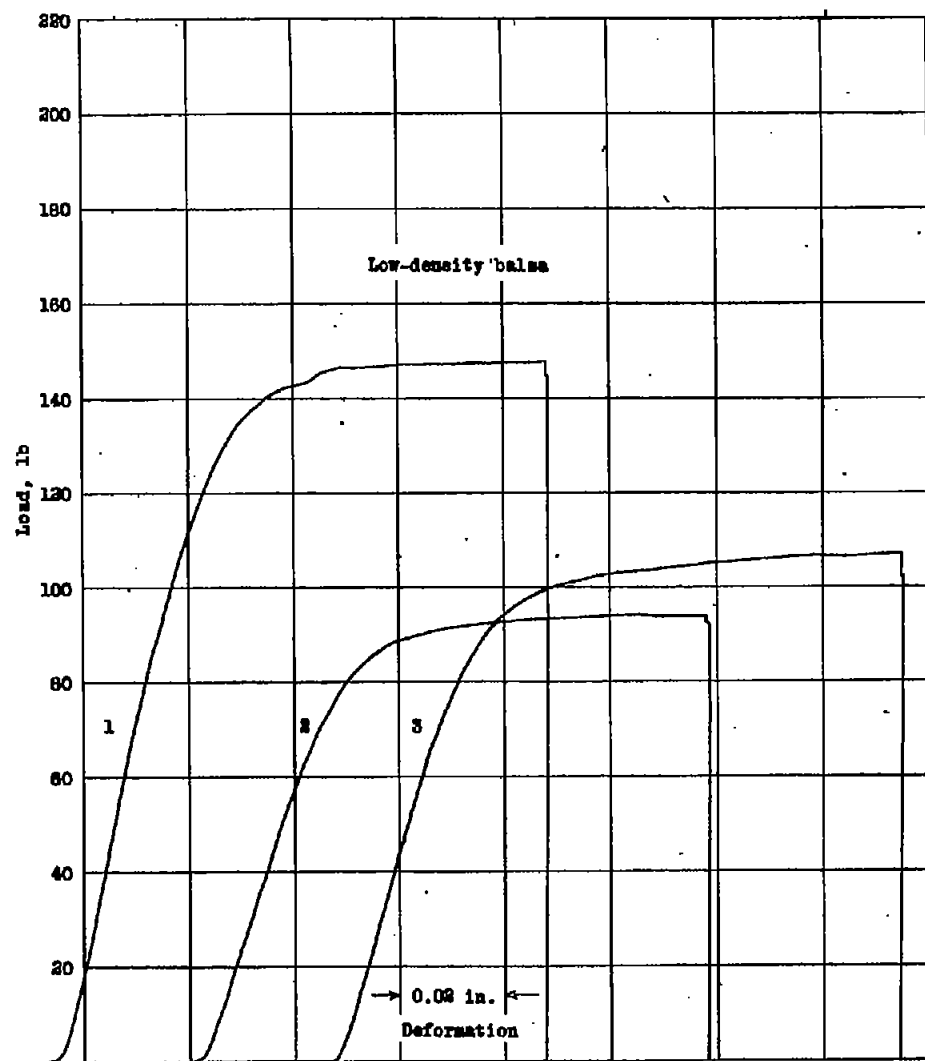
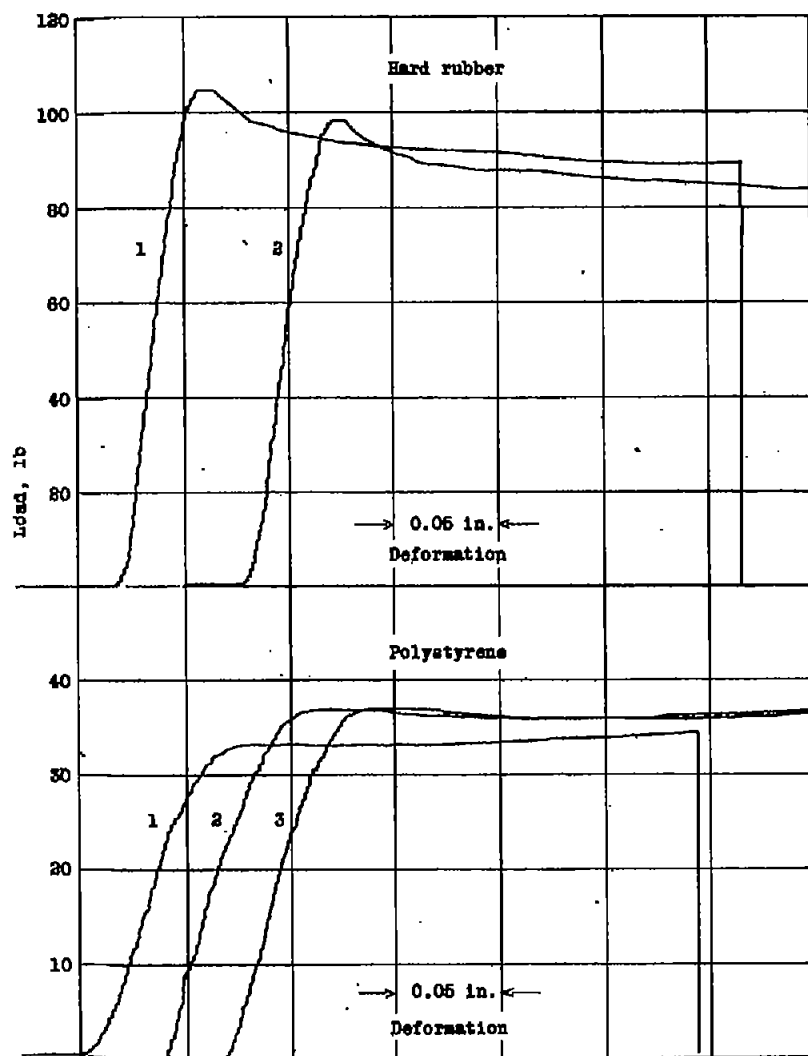


Figure 13.- Typical edgewise-compression load-deformation curves obtained with an automatic recorder. Specimens 2-by-2-by-1-inch were tested; a spherical head was used only for the low-density balsa, which was tested crosswise.